The Nature Conservancy®

Gulf Coastal Plain Ecosystem Partnership

APPENDIX H.

Gulf Coastal Plain Ecosystem Partnership

Steering Committee Meeting # 4

Conecuh National Forest
April 6-7, 2000

Research, Scientific and General Information

Conservation Planning
Gulf Sturgeon
Herbicides
Aquatic Woody Debris
Coastal Plain Streams
Biological Monitoring
Amphibians
Articles

Champion International • 4025 Highway 178 • Jay, Florida 32565 • 850 675-5760 • FAX 850 675-5756

GCPEP Steering Committee Meeting
April 6 – 7, 2000
Conecuh National Forest

Thursday April 6, 2000 DAY 1

TIME	TOPIC
9:00 am CST	Welcome & Meeting Logistics
9:10 am	Introduction of Partner Contacts
	GCPEP Operations
9:15 am	Job Accomplishments for Aquatic Specialist & Project Administrator
10:15 am	**Break**
10:30 am	Job Objectives for Project Conservation Ecologist
11:00 am	New & Current Partner Discussion
11:30 am	**Lunch at the Charter House (Buffet Style)**
	Major Project Updates
12:30 pm	Project Updates & Discussion
2:15 pm	Herbicide Impacts on Groundcover Report
2:45 pm	**Break**
3:00 pm	Deadhead Logging Update
3:30 pm	Blackwater River Watershed Report
4:00 pm	End of Meeting for Day 1

GCPEP Steering Committee Meeting
April 6 – 7, 2000
Conecuh National Forest

Friday April 7, 2000 DAY 2

TIME	TOPIC
9:00 am CST	Welcome & Meeting Logistics
9:10 am	Partner Updates Important Issues, Needs & Suggestions from Other Partners
10:15 am	**Break**
	Strategy & Action Identification
10:30 am	New Conservation Targets
	Meeting Wrap-up
11:30	Date Selection & Location for next Steering Committee Meeting
11:45	Evaluation
12:00-1:00 pm	**Lunch**
1:00-3:30 pm	Conecuh National Forest Tour

Gulf Coastal Plain Ecosystem Partnership

February PARTNERS QUARTERLY NEWS 2000

Greetings GCPEP Partners & Steering Committee Members!

We hope this finds you all well. Since we last saw you we have gotten all of our accounting, inter and intra-net and office systems installed and running. This took longer than expected, but, not nearly as long as it would have taken if we had moved our office.

Instead, Champion International generously extended our office space donation for another year. Thank you again to Arden, Ad and the Champion staff, especially at the Jay office, for the tremendous support they provide.

Tremendous gratitude must go out also to the Department of Defense, National Forests in Alabama and The Nature Conservancy for their funding support of GCPEP in 1999-2000.

Some of the partners expressed a desire to contribute supplies rather than funds to GCPEP. We will use this newsletter for our "Wish List". Thank you for your offer and we plan to take you up on it!

MAIL & SHIP ADDRESS

Gulf Coastal Plain Ecosystem Partnership (GCPEP)
4025 HIGHWAY 178
JAY, FL 32565

Please stop by and see us when you are in the neighborhood.

If any Partner has a GCPEP LOGO idea please contact Perrin.

The GCPEP staff will be working on the FY2001 Budget in February.

Vernon Compton
Project Director

Phone: (850) 675-5760
Fax: (850) 675-5756
gcpep@bellsouth.net

Stephanie Davis
Aquatic Specialist

Phone: (850) 675-2884
Fax: (850) 675-5759
gcpeph2o@bellsouth.net

Perrin Penniman
Project Administrator

**Phone: (850) 675-5758
**Fax: (850) 675-5759
**gcpepadm@bellsouth.net

** Please Direct ALL General Information To Administrator's Phone, Fax and Email.

PARTNERS QUARTERLY NEWS

Items received for the newsletter by the last day of the month will be sent out the first week of the next month.

FEB 29 for MARCH 2000

Please Send These Items to Administrator's Email

- Updated FACT SHEET for each Partner
- Upcoming EVENTS for the Next 3 Months (March, April, May) Please submit a list of Upcoming Events
- AWARDS & PROJECTS from the Past 3 Months (Dec., Jan. and Feb.) 1 or 2 paragraphs of Past Facts

Some of the things we have been doing since we last met:

Vernon

- With assistance from USFS and the Florida Trail Association, secured two large volunteer groups, (American Hiking Society Volunteer Vacation & FTA Heartland Chapter) to work on construction of the Eglin Trail
- Blackwater River Watershed Report and Road Restoration
- Research, Input and participation in DEP Working Group on deadheading in GCPEP rivers
- TNC Fire Management Meeting & Training
- Society of American Foresters Executive Committee Leadership Meeting
- Assisted in ANHP Draft Proposal to Conecuh National Forest for biological monitoring
- Worked with TNC and NWFWMD staff on possible Yellow River land acquisition

Stephanie

- Blackwater River Watershed Report and Road Restoration
- DEP Training on Biorecon sampling methods
- Deadhead Logging literature search & documentation
- Okaloosa Darter meeting discussing recovery efforts
- Visited aquatic sites on Eglin, Blackwater & Champion
- Apalachicola River & Bay duties

Perrin

- Training on budgets, grants, reporting, human resources, volunteer coordinating, marketing and communications
- GCPEP newsletter & presentation

Once we train our volunteers, we will lengthen the newsletter and use photographs.

We appreciate everyone's input about contents or appearance on this basic prototype.

Gulf Coastal Plain Ecosystem Partnership

MARCH **PARTNERS' QUARTERLY NEWS** 2000

Eglin Air Force Base; Blackwater River State Forest; National Forests in Alabama & Florida; Champion International; Northwest Florida Water Management District; The Nature Conservancy

GCPEP Staff

Vernon Compton
Project Director

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Fax: (850) 675-5756
gcpep@bellsouth.net

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4025 HIGHWAY 178
JAY, FL 32565

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MAY 31 for JUNE 2000

EGLIN AIR FORCE BASE
Natural Resources
By Carl Petrick

- EGLIN AFB Hosted the 6th annual Mobility Impaired Hunt. Fifty folks harvested 46 deer and 6 hogs. Everyone saw deer and had an opportunity to harvest a deer. Both hunts were highly controlled and were held in closed areas not normally open to public hunting.
- JACKSON GUARD BIOLOGISTS Carl Petrick and Justin Johnson assisted the Florida Fish & Wildlife Conservation Commission in a sting operation to apprehend 10 individuals who were hunting illegally in Eglin's closed areas. Two deer were confiscated and the 10 individuals will have all their outdoor recreation privileges revoked for at least 3 years.

NATIONAL FORESTS IN ALABAMA
Excerpt from "Pathways" By Joy Patty

Jim Gooder, a 22-year USDA Forest Service employee, has been selected as the forest supervisor for the four national forests in Alabama. He replaces John Yancey, who accepted a position with the U. S. Park Service earlier this year. Gooder brings with him a wealth of experience in forest management and is excited about his new assignment. Gooder earned a bachelor's degree in political science and business administration from the University of New Orleans in 1979. He has received a number of awards and recognition for his leadership in natural resources, including a Secretary of Agriculture Honor Award, two Forest Service Honor Awards, and numerous agency awards for outstanding performance. We welcome Jim and look forward to working with him on the Partnership.

CHAMPION INTERNATIONAL
By Ad Platt

Champion's Western Florida Region to experience 3rd Party SFI Program Review

Champion International Corporation recently opened the company's forest management practices to scrutiny in the nation's first-ever 3rd party audit of a company's forest operations under the American Forest & Paper Association's Sustainable Forestry Initiative Standards (SFI) (SM) verification program. This March, Champion's Western Florida Region in Cantonment, Florida is scheduled to be the fourth Champion location to undergo the rigorous review, led by Pricewaterhouse Coopers LLP, the world's largest professional services firm. The audit provides the opportunity to demonstrate both the demanding standards defined in the SFI program and Champion's clear commitment to lead the industry in improving resource stewardship.

Why SFI 3rd Party Verification

Champion is committed to public accountability of forest practices. Doing the right thing on all forest land and working cooperatively with others makes sense both from business and ecological perspectives as it:

CGPEP Conservation
Objectives (in priority order)

1. Conserve viable populations of target species
2. Introduce relatively natural fire regimes protecting key ecotypes
3. Protect urban interface and reduce fragmentation by use of conservation easements
4. Control erosion in ecologically sensitive areas
5. Manage recreation and public access
6. Increase communication, interaction and training among partners
7. Increase inventory and monitoring to further adaptive management
8. Increase public education and stakeholder involvement
9. Share resources
10. Secure outside funding and support
11. Inventory and control exotic species
12. Protect aquatic resources
13. Increase understanding of successful economic management of longleaf pine
14. Restore and manage the longleaf pine ecosystem
15. Recover the red-cockaded woodpecker
16. Game management
17. Conservation of examples of functional community types

Even Bigger News

UPM-Kymmene Corporation and Champion International Corporation have approved a merger agreement that would create a truly global paper and forest products company. The combined enterprise value is approximately $20.2 billion. The combined company will be called Champion International, symbolized by UPM-Kymmene's logo, the Griffin, and headquartered in Helsinki, Finland. The combined company will have manufacturing plants in 17 countries, sales and distribution in 50, and responsibility for the sustainable management of 15.8 million acres of forestlands worldwide.

GCPEP Activities

- Ad Platt, Buddy Minter, and Arden Shropshire of Champion joined Stephanie Davis on a tour of the watersheds within the "connector parcel" on February 3, looking for candidate streams to serve as possible benchmarks for water quality assessment studies.
- Early planning beginning for a possible cooperative burn of (potential) flatwoods salamander habitat later this summer.
- Discussions continued on formally establishing an agreement for the Florida Trails segment passing through the Champion "connector parcel".

THE NATURE CONSERVANCY
Stephanie Davis
Aquatic Specialist

- Aquatic site visit with Champion International staff
- Aquatic site visit to Conecuh National Forest with Alabama Natural Heritage Staff, National Forest in AL Aquatic Ecologist and TNC Protection
- Restoration pre-monitoring pictures, bio-monitoring and habitat assessment at Mare Creek with staff from the Blackwater River State Forest and FL Department of Environmental Protection
- Co-wrote and designed booklet and poster *A Guide to Understanding and Protecting the Blackwater River Watershed*
- Monitoring training with TNC's Florida State Ecologist
- Working on regional monitoring plan with Eglin AFB and US Fish & Wildlife Service
- Sampled insects on Eglin AFB with FL A&M University biologists
- Participated in TNC Freshwater Initiative planning retreat, SE Division staff retreat and International Science and Stewardship conference
- Met with national Freshwater Initiative staff, to discuss aquatic classification with U.S. Fish & Wildlife Service staff and FL Fish & Wildlife Conservation Commission staff
- Spoke to NW FL Canoe Club about deadhead logging

Conservation Value of GCPEP

- Despite being only 2% of the 42 million acre East Gulf Coastal Plain Ecoregion area, lands and waters included in the 840,000 acre Gulf Coastal Plain Ecosystem Partnership feature viable examples of 37% on 308 target species and 38% on 297 target natural communities identified for the ecoregion as a whole
- Protects >163 rare or imperiled plant, lichen, vertebrate and invertebrate species, including at least 40 G1-G2 species
- Encompasses 20-25% of the world's remaining large tracts of longleaf pine, including the largest public ownership's and more than 50% of the remaining old growth stands
- Features the highest quality barrier island complex on Florida's Gulf Coast
- The Choctawhatchee, Escambia-Conecuh and Yellow River watersheds and estuaries were identified as critical U. S> watershed hotspots (The Nature Conservancy 1998) including at least 59 globally rare or imperiled species, and the Escambia River contains the richest and most imperiled fish assemblage in Florida
- Includes >800,000 acres of public land, including Eglin AFB (463K ac), Blackwater River State Forest (191K ac), Northwest Florida Water Management District (98K ac) and Conecuh National Forest (83K)

- Discussion & literature searches on deadhead logging
- Preparing slide show and accompanying text on non-point source pollution and deadhead logging
- Apalachicola River and Bay duties

Vernon Compton
Project Director

- Attended two Deadhead Logging Technical Advisory Committee Meetings to finalize on recommendations on the environmental feasibility of removing pre-cut timbers from Florida rivers and creeks.
- Met with Student Conservation Association Eastern Program Development Director to discuss possible GCPEP projects.
- Met with Rob Sutter, TNC SE Division Conservation Ecologist on upcoming Eglin AFB Desired Future Condition Workshop.
- Completed Job Description for GCPEP Project Conservation Ecologist and began candidate search.
- Completed Final Report on Solutia / DEP In-Kind Penalty Payment. *A Guide to Understanding and Protecting the Blackwater River Watershed* was also a final product of this effort and was designed for community leaders and local politicians.
- Met with Longleaf Alliance on possible cooperative fuel classification system project.
- Finalized and met with TNC Florida Regional Staff on FY 2001 GCPEP budget and future budget needs.
- Hosted and Managed the American Hiking Society Volunteer Vacation at Eglin AFB. Crew completed 7 miles of trail construction and offered to assist in the future with GCPEP trail bridge needs.
- Met with Conecuh National Forest and Alabama Natural Heritage Program staff on a proposal for a five year biological monitoring program led by the ANHP with assistance

Perrin Penniman
Project Administrator

- Met with TNC Florida Regional Staff on FY 2001 GCPEP budget & future needs
- Distributing *A Guide to Understanding and Protecting the Blackwater River Watershed* to community leaders and local politicians
- Submitted pre-proposal for FY 2001 Legacy grant
- Preparing Final report for Solutia, Turner, Ft. Detrick, MD and Legacy
- GCPEP Quarterly News
- GCPEP Public Relations Departments

JOB DESCRIPTION

TITLE:	Project Conservation Ecologist
SUPERVISOR:	Gulf Coastal Plain Ecosystem Partnership Project Director
LOCATION:	Jay, Florida
PREPARERS:	Vernon Compton, Doria Gordon, Rob Sutter
DATE:	February 17, 2000
DURATION:	One Year (contingent upon funding)

SUMMARY OF POSITION:

The Conservation Ecologist will work for the Gulf Coastal Plain Ecosystem Partnership (GCPEP), a unique collaboration among Eglin Air Force Base (EAFB), The Nature Conservancy (TNC), Champion International Corporation, Blackwater River State Forest, the Northwest Florida Water Management District and National Forests in Alabama and Florida. Together the partners manage more than 840,000 acres of longleaf pine uplands and extensive bottomlands and streams in one of the most important conservation landscapes in the Southeast. The Conservation Ecologist will be responsible for synthesizing ecological information, conservation planning, establishing a monitoring program for the GCPEP conservation targets and for assisting in a Desired Future Condition workshop at EAFB and other workshops as scheduled.

DUTIES:

1. Synthesize ecological and conservation planning information for identified conservation targets at EAFB. Work with the TNC Southeast Division Conservation Ecologist, EAFB GIS and operational staff and other TNC staff to prepare background materials for an EAFB Desired Future Condition Workshop.

2. Take lead role in organizing EAFB Desired Future Condition Workshop and assist with workshop facilitation. Assist with organization of other workshops as scheduled.

3. Develop report on EAFB Desired Future Condition Workshop and work with Dr. Garry Peterson on completion of a landscape disturbance model for partner sites.

4. Work with GCPEP partners on conservation planning and development of site conservation plans for EAFB and other partner sites.

5. Write the ecological portions of GCPEP reports and other communication efforts geared toward specified audiences.

6. Assist the GCPEP staff in grant development and fundraising efforts.

7. Compile new scientific and management information at the species and community level for GCPEP sites.

8. Develop and implement monitoring programs for identified conservation targets.

9. Assist with other activities as requested by the Project Director.

GCPEP Conservation Targets

Species-Level Targets

Okaloosa darter
Florida bog frog
Gulf sturgeon
Red-cockaded woodpecker
Black bear
Flatwoods salamander
Aquatic fish/mussel complex
Game birds

Community/Ecosystem-Level Targets

Pitcher plant bogs
Barrier island complex
Estuarine systems
Ephemeral ponds
Sand pine scrub
Longleaf pine sandhill matrix
Longleaf pine flatwoods matrix
Seepage stream/slope complex
Blackwater rivers/streams
Alluvial rivers/streams

Site: Eglin AFB (east and west), Blackwater River State Forest, Conecuh National Forest, Champion International, Northwest Florida Water Management District

Name of Target: Pitcher plant bog

Description: Panhandle Florida and the adjacent lower Gulf Coastal Plain of Alabama and Mississippi contains some of the best remaining examples of pitcher plant bogs in the United States. These bogs contain many rare, endangered and endemic species. Folkerts (1982) estimates that nearly 97% of the original bog habitat has been destroyed throughout the Gulf Coastal Plain. Although wet most of the time, bogs may dry out during drought periods. In order to survive these drastic soil moisture changes, plants and animals must have specific adaptations. Bog plants must also be able to tolerate low pH and nutrient conditions. Pitcher plant bogs are found on Blackwater River State Forest, Champion International, Conecuh National Forest, Northwest Florida Water Management District, and Eglin Air Force Base. The main threats to pitcher plant bogs are hardwood encroachment caused by incompatible fire rotations or fire exclusion, habitat disturbance from equipment, and conversion of bogs to other land uses.

Stresses: Pitcher plant bogs

Stress	**Stress Rank**
Habitat destruction	**M**
Hardwood encroachment	**VH**
Soil disturbance	**H**
Altered hydrology	**M**

Sources of Stress: Pitcher plant bogs

Source of Stress	**Stresses**				
	Habitat destruction	Hardwood encroachment	Soil disturbance	Altered Hydrology	**Overall Threat Rank**
Incompatible fire management		H		H	**H**
Site conversion	H		H	H	**H**
Vehicle/equipment impacts			M	L-M	**M**
Incompatible well field management	H?			H?	**H?**
Exotic species	L-M?	L-M?		L-M?	**L-M?**
Recreation	L-M?		L-M?		**L-M?**
Illegal harvesting	L				**L**

Site: Eglin Air Force Base

Name of Target: Okaloosa darter

Description: Okaloosa darters were listed as federally endangered in 1973 under the Endangered Species Act. This darter is endemic to the Choctawhatchee Bay system (Okaloosa and Walton Counties, Florida) and the majority of its known range is within the borders of Eglin Air Force Base. The Okaloosa darter was originally listed due to its extremely limited range, and problems associated with water impoundments, sedimentation, and competition with brown darters. Okaloosa darters are typically found along the margins of small creeks fed by groundwater seeping from surrounding sandhills. They tend to avoid areas of low flow and open sand stretches with no cover. Woody debris, root mats and vegetation are used for spawning substrate. Where streams are impounded or subjected to heavy sedimentation, these darters have decreased in numbers and range. Both the Okaloosa darter and the potentially competitive brown darter are found in the Rocky Bayou system, but they appear to have reached a balance. Since the listing in 1973, numbers have decreased in several stream sections (Swift Creek and Mill Creek), but populations in the upper reaches of Boggy and Rocky Bayou stream systems appear stable. Eglin Air Force Base is actively working to restore clay pits and roads that are sources of sediment to darter streams and to modify culverts which have resulted in stream gradients detrimental to Okaloosa darters.

Stresses: Okaloosa darters

Stress	**Stress Rank**
Sedimentation	**H**
Groundwater depletion	**M-H?**
Habitat degradation	**H-VH**
Resource competition	**L-M?**
Flow alteration	**H-VH**

Sources of Stress: Okaloosa darters

Sources of Stress	**Stresses**					**Overall Threat Rank**
	Sedimentation	Groundwater depletion	Habitat degradation	Resource competition	Flow Alteration	
Incompatible road management	VH		VH		H	**VH**
Incompatible well fields		H?	M?		H?	**H?**
Brown darter				M?		**M?**
Impoundments	M-H		H		VH	**H**
Incompatible development	M	H?	H		M-H?	**H?**

DeeDee Ritchie
Florida House of Representatives, District 3

Dear Vernon,

I tried, unsuccessfully, to reach you by phone -

Thanks so much for your letter and the info. on Blackwater. Protection of our waterways is a priority issue for me.

Stay in touch - DeeDee Ritchie

111 Willing Street, Milton, Florida 32570-4973
Ph[illegible] (850) 983-5550 • Toll Free (888) 550-4560

3/20/00

Vernon,

Thanks you for all of you hard work. The guide was very well done. I appreciate you providing some solutions to the problems that are occurring. Thanks again — Jeff

Jeff Miller
State Representative • District 1

City of Milton

Office of the City Manager

March 15, 2000

Mr. Vernon Compton
Project Director
The Nature Conservancy
4025 Hwy. 178
Jay, FL 32565

Dear Vernon:

Thank you for providing me a copy of "A Guide to Understanding & Protecting the Blackwater River Watershed."

I enjoyed reading the booklet, and compliment those who worked on the project. It was very well done, and contains good information. I know we will be able to use it as a valuable resource.

The City of Milton is proud to partner with others in efforts to protect the Blackwater River.

I look forward to working with you.

Sincerely,

Donna S. Adams

Donna S. Adams
City Manager

DSA:lav

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P.O. Box 909 • 260 Dixon Street • Milton, Florida 32572 • (850) 983-5400 • Fax (850) 983-5415
~ Established 1844 ~

City of Milton

Office of the Mayor

March 29, 2000

Mr. Vernon Compton
Project Director
The Nature Conservancy
4025 Hwy 178
Jay, FL 32565

Dear ~~Mr. Compton~~: Vernon

Thank you for sharing with me the guide to understanding and protecting the Blackwater River water shed.

I am very impressed with its quality and information. This is a very fine piece of work, which I wish all citizens could see.

I certainly agree with the solutions outlined on the pages you mentioned. Please, be assured that I am in total support of efforts to assure the protection of our river.

The City has worked hard through its storm water committee to make a difference and we understand much more needs to be done.

Thank you for your interest and assistance.

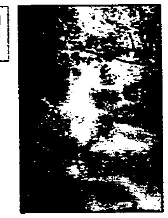
Sincerely,

Guy Thompson
Mayor

GT/rff

P.O. Box 909 • 260 Dixon Street • Milton, Florida 32572 • (850) 983-5400 • Fax (850) 983-5415
~ Established 1844 ~

Understanding and Protecting the Blackwater River Watershed



The Blackwater River is prized for its tea-colored waters, white sandbars and recreational opportunities. Residents and visitors alike enjoy canoeing, fishing, hunting and wildlife viewing along the Blackwater River.

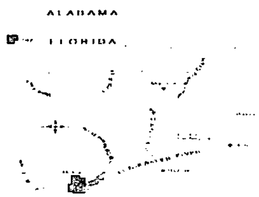
However, as the river and its surrounding lands become more popular, the Blackwater River watershed will face pressures that could limit its ability to provide the resources that we depend on for our recreation and livelihood. To address these and other challenges, we must understand the river's history, its vegetation and wildlife, and what we can do to protect it.

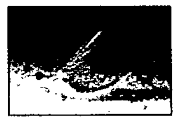
The Blackwater River and its Watershed

All of the water that drains into the Blackwater River makes up its watershed. Approximately 860 square miles of land comprise the Blackwater River watershed, including the land area of its three major tributaries– Juniper Creek, Coldwater Creek and Pond Creek.

The river flows mainly through protected forests including Conecuh National Forest, Blackwater River State Forest and Blackwater River State Park. However, pockets of managed agricultural and silvicultural lands and areas of urban and suburban development, including the communities of Baker, Bradley, Jay, Holt, Harold, Milton and Munson are also located in the river's watershed. All activities within this large area affect the Blackwater River. Therefore, the health of the river depends on how these lands are managed.

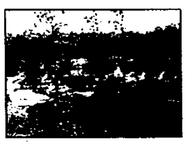
The Blackwater River is one of the best remaining examples of a shifting, sand-bottomed river in the United States, and the watershed is home to many species of plants and animals that are considered rare, threatened or endangered. These plants and animals depend on clean water and good habitat for survival.





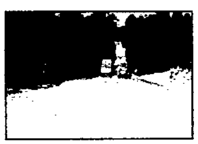
Challenges

- Accelerated Erosion
- Nutrient Enrichment
- Elevated Bacterial Levels
- Decreased Water Quantity
- Removal of Woody Debris
- Litter and Dumping
- Toxic Chemicals
- Flow Alteration



Sediment from this gully washes into the river

Many farmers fence out cattle to prevent sediment, nutrient and bacterial inputs into creeks



Sediment from this road washes into a creek that feeds the Blackwater River

Litter and dump sites are expensive to clean up

Rope marks deadhead log for removal

These culverts are too small for this stream.

When bridges and culverts are too small for a stream, often they are washed out during heavy rains.

Working Together to Protect the Blackwater River Watershed

In order to keep the Blackwater River healthy, we must reduce habitat and water quality degradation by continually improving our land-use practices. Only then will we be able to ensure that the Blackwater River will be both productive and healthy for future generations. By working together, we can protect the Blackwater River watershed. Listed below are some steps we can take to restore and protect the Blackwater system.

•Develop and implement a regional plan to address water quality and quantity issues.

•Provide an adequate number of trash cans at boat launches and bridges and increase enforcement for littering and illegal dumping.

•Promote widespread education about septic tanks and support the extension of city water and sewer lines wherever feasible.

•Evaluate culverts, roads and bridges and replace with structures that allow natural flow.

•Enforce stormwater runoff regulations for road and building construction sites.

•Pave and improve roads where appropriate.

Road closed so that a nearby creek can recover from erosion

•Close badly eroded roads and establish maintenance standards for roads that remain open.

•Encourage programs that provide funding for Best Management Practices (BMPs) on pastures and croplands.

Hay bales and newly planted trees help control erosion from an old road.

Woody debris is important habitat for fish and insects

•Encourage voluntary BMPs on private lands.

•Require a thorough environmental impact study before allowing the removal of woody debris.

•Create streamside buffer zone requirements.

•Discourage building in the floodplain.

•Seek funds to build more wooden canoe launches.

•Support land managers as they strive to balance adequate public access with the protection of natural resources.

Re-vegetated riverside area helps to stop erosion

Volunteers plant grasses and trees to prevent erosion near a small stream

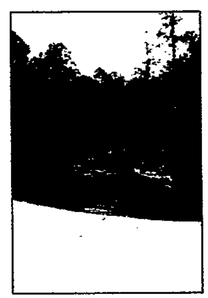
•Ensure adequate funding for enforcement, restoration and monitoring.

•Support organizations and partnerships that focus attention on watershed issues and are working to reduce threats to the Blackwater River watershed.

We All Play a Role

There is a high cost to restoring environmentally damaged areas, repairing eroded roads and cleaning up litter and illegal dump sites. Most people love the Blackwater River and the lands surrounding it and use these areas responsibly.

The protection of these valuable natural resources requires responsible use on public and private lands so that future generations can enjoy the forests and waters of the Blackwater River watershed.



Thanks to the Florida Department of Environmental Protection and The Nature Conservancy for their support. Pictures were provided by Tom Arrington, Vernon Compton, Stephanie Davis, Tom Fink and Donald Ray.

www.PensacolaNewsJournal.com

PENSACOLA News Journal

FRIDAY, APRIL 21, 2000

LOCAL

FRIDAY, APRIL 21, 2000

Guide's goal is to protect Blackwater River

By Anton Caputo
News Journal staff writer

With the Blackwater River acting as a drainage basin for most of north Santa Rosa County and part of South Alabama, the Nature Conservancy wants people to be careful how they treat the land.

From pesticides and herbicides to dirt and clay, the environmental group is worried about an influx of pollutants choking off the river and its habitat. So the group has prepared a guide to protecting the river system and plans to hold workshops this summer to promote environmentally friendly land management.

"An educational effort like this is only good if you can get it out to people," said Vernon Compton, Nature Conservancy project director.

A vast array of pollutants endanger the river, but Compton is particularly worried about the tons of dirt and clay washed into the river every year from unpaved roads.

There are more than 1,000 miles of such roads in the Blackwater River State Forest alone. With 500,000 people a year using them for recreation, they're eroding quickly.

The Blackwater State Forest is mapping its roads this summer with an eye toward closing the unnecessary ones, particularly those that run close to rivers and streams.

Forestry Center manager John Webster said the plan boils down to installing drainage culverts and ditches on some roads and keeping people off others so Mother Nature can grass them over. The vegetation acts as an anchor for the dirt and helps prevent erosion.

Compton hopes the public cooperates.

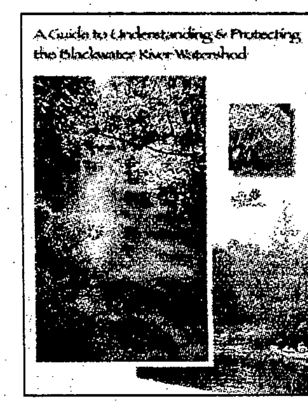
"Of course that might affect people using the river," he said. "But they need the support of the public when they make the tough decisions."

Charles D'Asaro, a Bagdad resident and University of West Florida marine biologist, thinks the publication is a good guide for Blackwater River land management. But he'd like to see people go further and begin paying attention to the damage industrial pollution is causing in the lower portion of the river.

Webster said the guide is a good start and hopes people take the conservancy's advice seriously.

Want a copy?

To obtain "A Guide to Understanding & Protecting the Blackwater River Watershed," call 850-675-5758.



This guide book hopes to protect Blackwater River.

Mare Creek

Mare Creek

Mud Hole Near Mare Creek

Mud Hole with Go Around

East River Road Ford on Mare Creek

Mud Hole on East River Road

STATE OF FLORIDA
DEPARTMENT OF ENVIRONMENTAL PROTECTION
PHYSICAL/CHEMICAL CHARACTERIZATION FIELD DATA SHEET (5/21/98v2)

SUBMITTING AGENCY CODE: **8010** SUBMITTING AGENCY: **FDEP NWD**	STORET STATION NUMBER: **33030109**	DATE: **2/9/00**	TIME: **0930-1430**	RECEIVING BODY OF WATER: Mare Creek, Blackwater River, Pensacola Bay

REMARKS: **BRSF/GCPEP BioRecon. Digital photos**	COUNTY: **Okaloosa**	LOCATION: **Mare Creek ford "East" River Road SW section 26**	FIELD NAME: **GCPEPMareCfordpc. doc**

RIPARIAN ZONE/INSTREAM FEATURES

Predominant Land-Use in Watershed (specify relative percent in each category):

Forest/Natural	Silviculture	Field/Pasture	Agricultural	Residential	Commercial	Industrial	Other (specify)
	x						**hunting**

Local Watershed Erosion:	None: ☐	Slight: ☐	Moderate: ☐	Heavy: ☒
Local Watershed NPS Pollution:	No evidence: ☐	Slight: ☐	Moderate potential: ☐	Obvious sources: ☒

Width of riparian vegetation (m) on least buffered side:**0**	List & map dominant vegetation on back **AWC blackgum mt.laurel sweetbay redmaple**	Typical Width (m)/Depth (m)/Velocity (m/sec) Transect **3.2 m wide**
Artificially Channelized No Artificially Impounded No	**none**	**0.2 m/s** / **0.55 m deep**; **0.3 m/s** / **0.55 m deep**; **0.2 m/s** / **0.325 m deep**
High Water Mark **1** (m above present water level)	**1.1** (present depth in m)	**2.1** (m above bed)

Canopy Cover %:	Open: ☐	Lightly Shaded: ☒ (11-45%)	Moderately Shaded: ☐ (46-80%)	Heavily Shaded: ☐

SEDIMENT SUBSTRATE

Sediment Odors:	Normal: ☐	Sewage: ☐	Petroleum: ☐	Chemical: ☐	Anaerobic: ☐	Other: ☒ **slight H2S**
Sediment Oils:	Absent: ☒	Slight: ☐	Moderate: ☐	Profuse: ☐		
Sediment Deposition:	Sludge: ☐	Sand smothering: **none**	Silt smothering: **severe**	Other: ☐		

Substrate Types	% coverage	# times sampled	method	Substrate Types	% coverage	# times sampled	method
Woody Debris (Snags)	**36 (1available)**	**2**	**dipnet**	Sand	**20**		
Leaf Packs or Mats	**4**	**0.5**	**dipnet**	Mud/Muck/Silt/clay	**36**		
Aquatic Vegetation				Other:			
Rock or Shell Rubble				Other:			
Undercut banks/Roots	**4 (2 available)**	**1.5**	**dipnet**	**Draw aerial view sketch of habitats found in 100 m section.**			

Water Quality	Depth (m):	Temp. (°C):	pH (SU):	D.O. (mg/l):	Cond. (μmho/cm) or Salinity (ppt):	Time		Secchi (m):
Top								
Mid-depth	**0.2**	**8.8**	**5.8**	**10.77**	**31**	**0955**	**91% DO sat.**	**1.1 TB**
Bottom								

System Type:	Stream: ☒ **2nd-3rd order**	Lake: ☐	Wetland: ☐	Estuary: ☐	Other:
Water Odors:	Normal: ☒	Sewage: ☐	Petroleum: ☐	Chemical: ☐	Other: ☐
Water Surface Oils:	None: ☒	Sheen: ☐	Globs: ☐	Slick: ☐	
Clarity:	Clear: ☒	Slightly Turbid: ☐	Turbid: ☐	Opaque: ☐	
Color: **slight**	Tannic: ☒	Green (algae): ☐	Clear: ☐	Other: ☐	

Weather Conditions/Notes:Clear 30's-60's F. La Nina warm/dry conditions for past 2 years. No rain last 11 days.
Substrates covered with film of clay from road's stream ford 37% of habitat, 36% of bottom smothered with clay/silt with another 10% sand (83% habitat smothering.
mosses/liverworts

Abundance	Absent	Rare	Common	Abundant
Periphyton Batrachospernum	☐	☐	☒	☐
Fish darters, Notropis	☐	☐	☒	☐
Aquatic Macrophytes	☒	☐	☐	☐
Iron/sulfur Bacteria	☒	☐	☐	☐

Sampling Team: **Donald Ray, Stephanie Davis, Clarence Morgan**	Signature:	Date: **02/09/00**

State of Florida
Department of Environmental Protection
Freshwater Benthic Habitat Assessment Field Data Sheet (form version 9-18-98)

SUBMITTING AGENCY CODE: 8010 SUBMITTING AGENCY NAME: FDEP Northwest District	STORET STATION NUMBER:	DATE: (m/d/y) 2/9/00	RECIEVING BODY OF WATER: Mare Creek Blackwater River Pensacola Bay
REMARKS: BRSF/GCPEP BioRecon dirt road restoration (bridge to span stream/wetlands to replace ford	COUNTY: Okaloosa	LOCATION: **Mare Creek ford "East" River Road SW Section 26**	FIELD ID/NAME: Marecrkfha.pc

Habitat Parameter	Optimal	Suboptimal	Marginal	Poor
Substrate Types & Availability 7	Greater than 30% snags, logs, tree roots, aquatic vegetation, leaf packs (partially decayed), undercut banks, rock, or other stable habitat. 20 19 18 17 16	16% to 30% snags, logs, tree roots, aquatic vegetation, leaf packs, etc. Adequate habitat. Some substrates may be new fall (fresh leaves or snags). 15 14 13 12 11	5% to 15% snags, logs, tree roots, aquatic vegetation, leaf packs, etc. Less than desirable habitat, frequently disturbed or removed. 10 9 8 7 6 **7%**	Less than 5% snags, logs, tree roots, aquatic vegetation, leaf packs, etc. Lack of habitat is obvious, substrates unstable or smothered. 5 4 3 2 1 0
Water Velocity 20	Max. observed at typical transect: > 0.25 m/sec. but < 1 m/sec. 20 19 18 17 16 **0.3**	Max. observed at typical transect: > 0.1 to 0.25 m/sec. 15 14 13 12 11	Max. observed at typical transect: 0.1 to 0.5 m/sec. 10 9 8 7 6	Max. observed at typical transect: < 0.05 m/sec., or spate occuring; > 1 m/sec. 5 4 3 2 1 0
Artificial Channelization 20	No artificial channelization or dredging. Stream with normal, sinuous pattern. 20 19 18 17 16	May have been channelized in the past (>20 yrs), but mostly recovered, fairly good sinuous pattern. 15 14 13 12 11	Channelized somewhat recovered, but > 80% of area affected. 10 9 8 7 6	Artificially channelized, box-cut banks, straight, instream habitat highly altered. 5 4 3 2 1 0
Habitat Smothering 4	Less than 20% of habitats affected by sand or silt accumulation. 20 19 18 17 16	20% - 50% of habitats affected by sand or silts accumulation. 15 14 13 12 11	Smothering of 50% - 80% of habitats with sand or silt, pools shallow, frequent sediment movement 10 9 8 7 6	Smothering of > 80% of habitats with sand or silt, a severe problem, pools absent. 5 4 3 2 1 0 **83%**
Bank Stability 9	Stable. No evidence of erosion or bank failure. Little potential for future problems. 20 19 18 17 16	Moderately stable. Infrequent or small areas of erosion, mostly healed over. 15 14 13 12 11	Moderately unstable. Moderate areas of erosion, high erosion potential during floods. 10 9 8 7 6 **erosion around cut**	Unstable. Many (60% - 100% raw, eroded areas. Obvious bank sloughing. 5 4 3 2 1 0 **stumps**
Riparian Buffer Zone Width 9	Width of native vegetation (least buffered side) greater than 18m. 20 19 18 17 16	Width of native vegetation (least buffered side) 12m to 18m. 15 14 13 12 11	Width of native vegetation 6 to 12m, human activities still close to system. 10 9 8 7 6 **recent cut stumps on both banks.**	Less than 6m of native buffer zone due to intensive human activities. 5 4 3 2 1 0 **clearcut to 0-6 meters in 10 meter section**
Riparian Zone Vegetation Quality 18	Over 80% of riparian surfaes consist of native plants,, including trees, understory shrubs, or non-woody macrophytes. Normal, expected plant community for given sunlight & habitat conditions.**middle aged AWC, mt.laurel, cutover** 20 19 18 17 16	50% to 80% of riparian zone is vegetated, and/or one class of plants normally expected for the sunlight & habitat conditions is not represented. Some disruption in community evident. 15 14 13 12 11	25% to 50% of riparian zone is vegetated, and/or one or two expected classes of plants are not represented. Patches of bare soil or closely cropped vegetation, disruption obvious. 10 9 8 7 6	Less than 25% of streambank surfaces are vegetated and/or poor plant community (*e.g.* grass monoculture or exotics) present. vegetation removed to stubble height of 2 inches or less. 5 4 3 2 1 0

87 TOTAL SCORE **62 % SIMILARITY TO REFERENCE SCORE** (65% biometric threshold)	Comments Selected large trees logged from both banks. Cleared to 6 meters of both banks. 0 buffer width at 10 meter section. Excellent potential for recovery if wetlands bridged & riparian zone not cut.

ANALYSIS DATE: **2/9/00**	ANALYST: **Donald Ray, Stephanie Davis, Clarence Morgan**	SIGNATURE:

State of Florida Dept. of Environmental Protection

BioRecon Assessment (form version 11-19-98)

STORET Station 33030109	Location Mare Creek below ford "East" River Road SW corner Section 26
Latitude: N30 ° 54 ' 14.7 " Longitude: W86 ° 42 ' 59.1 "	Watershed / Basin Mare Creek, Blackwater River /Pensacola Bay
Date/Time Collected 02/09/00 1000-1400	Collected & ID'ed By Donald Ray, Stephanie Davis, Clarence Morgan
Taxa found in 4 sweeps: Woody debris, undercut banks/roots, & leaf packs were the 3 types of habitats sampled;	4 hours picking & ID time.

** Rare (1-3), Common (4-10), Abundant (11-100), Dominant (>100).

Taxa	FI	Tally	Abun Code
Diptera			
Ceratopogonidae			
Culicidae			
Empididae			
Other Chironomidae			A
Rheotanyarsus sp.	2		R
Simulium sp.	2		A
Stenochironomus sp.	2		R
Stratiomyidae			
Tipulidae 2 spp.			R
Tabanidae			R
Gastropoda			
Ancylidae			
Elimia sp.			
Physella sp.			
Planorbella sp.			
Hydrobiidae			
Viviparus			
Odonata			
Argia sp.	2		C
Boyeria sp.	2		C
Calopteryx sp.	2		R
Enallagma sp.			
Gomphus sp.	1		
Hetaerina sp.	2		
Ischurna sp.			
Libellulidae			
Macromia sp.	2		R
Neurocordulia sp.	1		C
Progomphus sp.	2		
Hagenius brevistylus			R
Dromogomphus sp.			R
Coleoptera			
Ancyronyx variagatus			
Curculionidae			
Dineutes			C
Dubiraphia sp.			
Dytiscidae			
Gyretes sp.			
Microcylloepus sp.			
Stenelmis sp. antennalis			R
Gonielmis dietrichi			C
Hydrophilidae			R
Column Total: FI/Taxa	15	17	

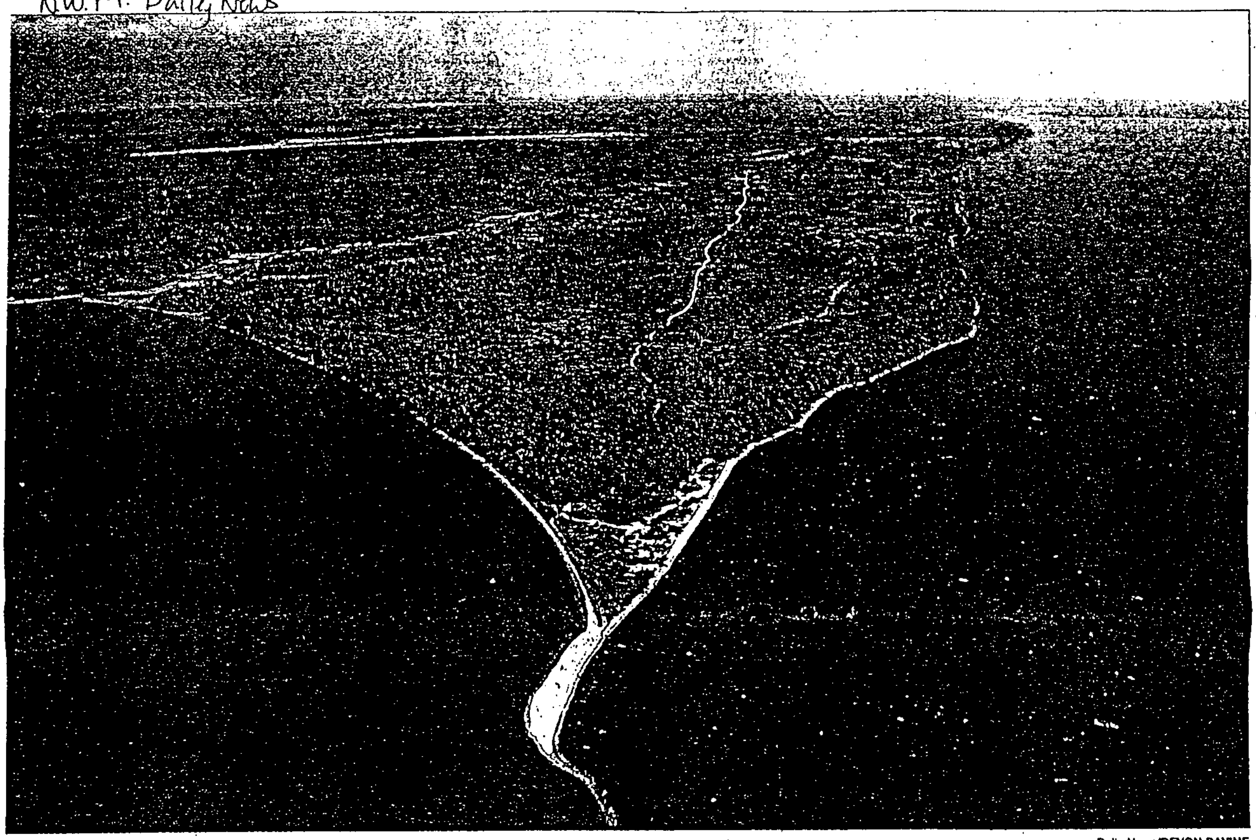
Taxa	FI	Tally	Abun Code
Trombidiformes			
Acarina			
Oligochaeta			R
Naiidae			
Tubificidae			
Hirudinea			
Pelecypoda			
Corbicula sp.			
Elliptio sp.			
Pisidiidae			
Megaloptera			
Corydalus cornutus	2		R
Sialis sp.			
Nigronia sp.			
Hemiptera			
Belostoma sp.			
Corixidae			
Hydrometra sp.			
Pelocoris sp.			
Pleidae			
Ranatra sp.			
Veliidae			
Other (name groups)			
Nematoda		x	
Decapoda			
Palaemonetes sp.	1		
Procambarus sp.			C
Amphipoda			
Gammarus sp.	1		
Hyalella azteca			
Crangonyx sp.			R
Isopoda			
Caecidotea (Asellus)	1		
Column Total: FI/Taxa	2	4	

Taxa	FI	Tally	Abun Code
Ephemeroptera			
Baetis sp.			
Baetisca sp.			
Caenis sp.			
Callibaetis sp.			
Centroptilum sp.			
Heptagenia sp.			
Hexagenia sp.			R
Isonychia sp.			R
Leptophlebia sp. intermedia			C
Neoephemera sp.			
Stenacron sp.	1		R
Stenonema sp. smithae	2		C
Tricorythodes sp.	1		
Eurylophella doris			C
Acerpenna pygmacea			C
Habrophlebiodies brunneipe.			C
Plecoptera	2		
Acroneuria sp. c.f. arenosa	2		R
Amphinemura sp.	2		
Hydroperla sp.	2		
Isoperla sp.	2		
Leuctra sp.	2		
Neoperla sp.	2		
Paragnetina sp.	2		
Perlesta sp.	2		C
Perlinella sp.	2		
Pteronarcys sp.	2		
Taeniopteryx sp.	2		
Talloperla sp.	2		
	2		
	2		
	2		
Trichoptera			
Anisocentropus sp.			R
Brachycentrus sp.	2		
Cheumatopysche sp.	1		C
Chimarra sp.	2		R
Diplectrona sp.			
Hydroptila sp.	2		C
Hydropsyche sp.	2		R
Lype diversa			R
Macrostemum sp.	2		
Nectopysche sp.	1		
Oecetis sp.	1		
Oxyethira sp.	2		
Polycentropus sp.	2		
Triaenodes sp.			
Phylocentropus sp. case			
Column Total: FI/Taxa	14	16	

BIOMETRICS	Value	Thresholds for impairment rating: Panhandle West	Panhandle East	Peninsula	NE	
						If 3metrics are > target values, site is Healthy ☐
						If 2metrics are within target values, site is Suspect ☒
Site Total Taxa Richness	37	≥24	≥24	≥18	≥17	
Site Total Florida Index	31	≥22	≥19	≥10	≥6	If less than 2 metrics are within target values, site is
Site Total EPT	16	≥17	≥9	≥4	≥3	[illegible]

A PARADISE, LOST?

NW. Fl. Daily News 1/23/00



Daily News/DEVON RAVINE

Isolated by the Eglin Air Force Base reservation, Santa Rosa County's Escribano Point is home to a diverse collection of high-quality wetlands, oak hammocks, scrubby pine flatwoods and sea grass beds. A Louisiana developer is seeking an easement from Eglin to access the property and develop approximately 940 acres on the point.

Escribano Point is largely untouched by development, but that may change

By DUWAYNE ESCOBEDO
Daily News Staff Writer

ESCRIBANO POINT — A stand of gangly, moss-draped oak trees with trunks too massive to hug runs along the coastline, framing the clear, calm waters of East Bay.

Further inland, scrubby pine flatwoods and impenetrable marshy prairies harbor sanctuaries of rare plants.

Like a butter knife teetering over the water's edge, Escribano Point stands out in this scene of natural beauty.

One of the last undisturbed tracts of private waterfront property in Northwest Florida, the land surrounding the point remains largely inaccessible because it backs up to the Eglin Air Force Base reservation.

By this summer, however, it could be carved into an upscale development complete with a golf course, marina and large homes.

The decision to develop or preserve will be made by then, according to Porter Horgan, who owns more than 1,000 acres of the 6,914-acre parcel adjacent to the point.

The owner of Hammond, La.-based Amerivest Mortgage Services Inc., Horgan began lobbying local government and military authorities six months ago to bring running water, power, telephone lines, a paved road and other basics to the remote area located about seven miles west of State Road 87.

"It's one of the most beautiful properties I've ever owned and

Please see POINT/A4

Daily News/DEVON RAVINE

A dog drinks from the East Bay near the only permanent settlement on Escribano Point. A handful of residents live on the point without the benefit of electricity, telephone or sewer service.

Home is where he squats, and he's not inclined to stand up

Daily News/DEVON RAVINE

Horace Smith (left) and his brother-in-law Jerry Spence sit in front of Smith's home on East Bay, a little north of Escribano Point.

By DUWAYNE ESCOBEDO
Daily News Staff Writer

ESCRIBANO POINT — Horace Smith's small television relies on power from two car batteries and rabbit-ear antennas for reception that rivals cable.

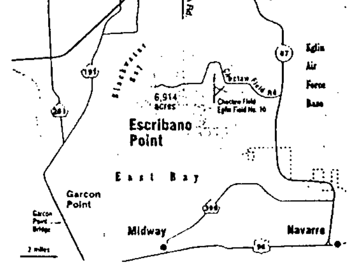
The kitchen stove, which he uses to cook up cans of Hormel chili, runs off a propane tank. He pumps water by hand to wash the dishes stacked in a kitchen sink on a dilapidated counter on his back porch.

Heat comes from a wood stove fueled by logs lining one wall of his bedroom on Blackwater Bay. Four kerosene lamps and candles light up his place at nighttime.

The 70-year-old squatter has hung his hat here for about 40 years and doesn't intend to leave anytime soon.

"It's sold two or three times and I'm still here," he said, resting under a giant oak tree near the white sandy beach in front of the rustic two-story house he built. "I want just what I got. I go to bed when I want to, get up when I want to. I'm not used to any of that modern stuff. I don't want that."

Please see HOME/A4



Daily News/KEN MAINES

POINT

From A1

one of the most beautiful I've ever been to," said Horgan, whose company bought much of the land, which includes three miles of coastline north of Escribano Point, for $500,000 in 1997. "It'd be just gorgeous for home sites. Personally, I'd like to see it left in its natural state as a park. But I cannot afford to donate an acre. One way or another, it's all going to happen this year."

From time to time during the 20th century, efforts have been made to attract more residents to Escribano Point. A few houses have even gone up.

Escribana Shores, a 20-lot, 100-acre subdivision, was platted adjacent to the U.S. Navy's airstrip, Choctaw Field, in 1977, but never built.

Individuals on Blackwater Bay own a handful of lots, accessible by one clay road maintained by Santa Rosa County. Just four rustic, two-story homes and a travel trailer make up the neighborhood now, and only 70-year-old squatter Horace Smith is a year-round resident.

Richard Hilsenbeck has seen the property firsthand and is working for the Nature Conservancy in Florida to keep much of the land around Escribano Point untouched by bulldozers.

"There's an urgency here to preserve it," Hilsenbeck, the group's associate director of protection said from Tallahassee. "The area is so scenic and has a beautiful coastline, which unfortunately makes it attractive to development. But the best use for the citizens of Florida would be as a recreation area."

The Florida Department of Environmental Protection first put the site on its priority list to purchase for preservation in 1994 but the agency has run into resistance from large landowners, who reportedly cling to dreams of the millions development could bring.

The state currently ranks it 28th on its list of projects statewide. DEP estimates the assessed value of the entire area — which includes a bulk of wet prairie with rare Panhandle lilies, White-top pitcher-plants, Chapman's butterworts and other plants — at nearly $2.9 million.

Beginning in July, Gov. Jeb Bush's Florida Forever initiative will commit $300 million for the next 10 years for acquisition and restoration of environmentally sensitive lands.

Because of its isolation, the extensive permitting required to build, the high cost to furnish utilities and Eglin's desire to protect its mission from buildup around its reservation, snapping up the area for conservation has been a low priority so far.

In 1996, the state paid $850,000 for 208 acres just north of Escribano Point near the mouth of the Yellow River.

Until now, logging, which has left several large clear-cut patches dotting the area, has been the biggest threat to the environment.

"That's one of the last undeveloped, unharmed areas in that part of the world," said Bill Cleckley, the Northwest Florida Water Management District's director of land management and acquisition. "Its greatest protection has been its isolation. But we realize there's very little waterfront left and if someone has the dollars it could be subject to development pressures."

Besides Amerivest, three others control a bulk of the pristine area and its sandy white coastline:

- Ashton Graybiel Jr., a Pensacola doctor, has more than 650 acres, including land on the coast south of Fundy Bayou, which encompasses Escribano Point.
- Eric White, another doctor from Cape Coral, controls more than 625 acres, which includes a large tract south of Escribano Point, running along East Bay.
- Dale Rice Sr., a Crestview attorney, holds more than 320 acres in the area.

Santa Rosa County Administrator Hunter Walker and Amerivest representatives met last summer with Eglin officials to seek expanded right of way to help bring utilities to Choctaw Field Road more easily and to gauge the military's support for development.

"We don't mind developing as long as it doesn't damage the military's mission," Walker said. "I am somewhat sympathetic to Mr. Horgan. If he cannot use it, then the (government) needs to buy it from him."

Eglin officials have deferred a final decision until the base finishes updating its Gulf Range 2025 Strategic Plan. The plan outlines its needs for Choctaw Field. The Navy is also working on an environmental assessment of the field.

In a Sept. 7, 1999, letter to Santa Rosa County, Robert Arnold, Eglin's Encroachment Committee chairman, listed seven conditions for development should the base approve expanding Choctaw Field Road's easement.

Among the restrictions were:

- Notifying future buyers it would be a high-noise, high-accident potential area.
- Requiring the county to change its building code to require measures lowering noise on the properties west of Choctaw Field.
- Limiting density to one home per acre on all Escribano Point lands.

Horgan, the Louisiana developer, is optimistic about development plans. He estimates that in today's market Amerivest's three-plus miles of coastline could yield an estimated $15 million in sales.

"We're not going full speed ahead yet on this," he said. "But people we've contacted have been extremely cooperative. We do have constraints. But developers have shown interest. It is the largest privately owned waterfront accessible place west of Destin."

The last reported community on Escribano Point was a band of 41 Indians recorded in 1937 by American Indian Agent Archibald Smith. Known as Blackwater Indians, they took fish and oysters to Pensacola markets. The small community included two very old Spaniards, possibly Louis Maestro and Antonio Garcia, who were the first landowners in the Escribano Point area.

Indians are thought to hav inhabited the area as much as 50 years before the Spanish surveye East Bay in 1693. Archaeologist have discovered a rich Nativ American history around the poin with a dozen prehistoric buri mounds located.

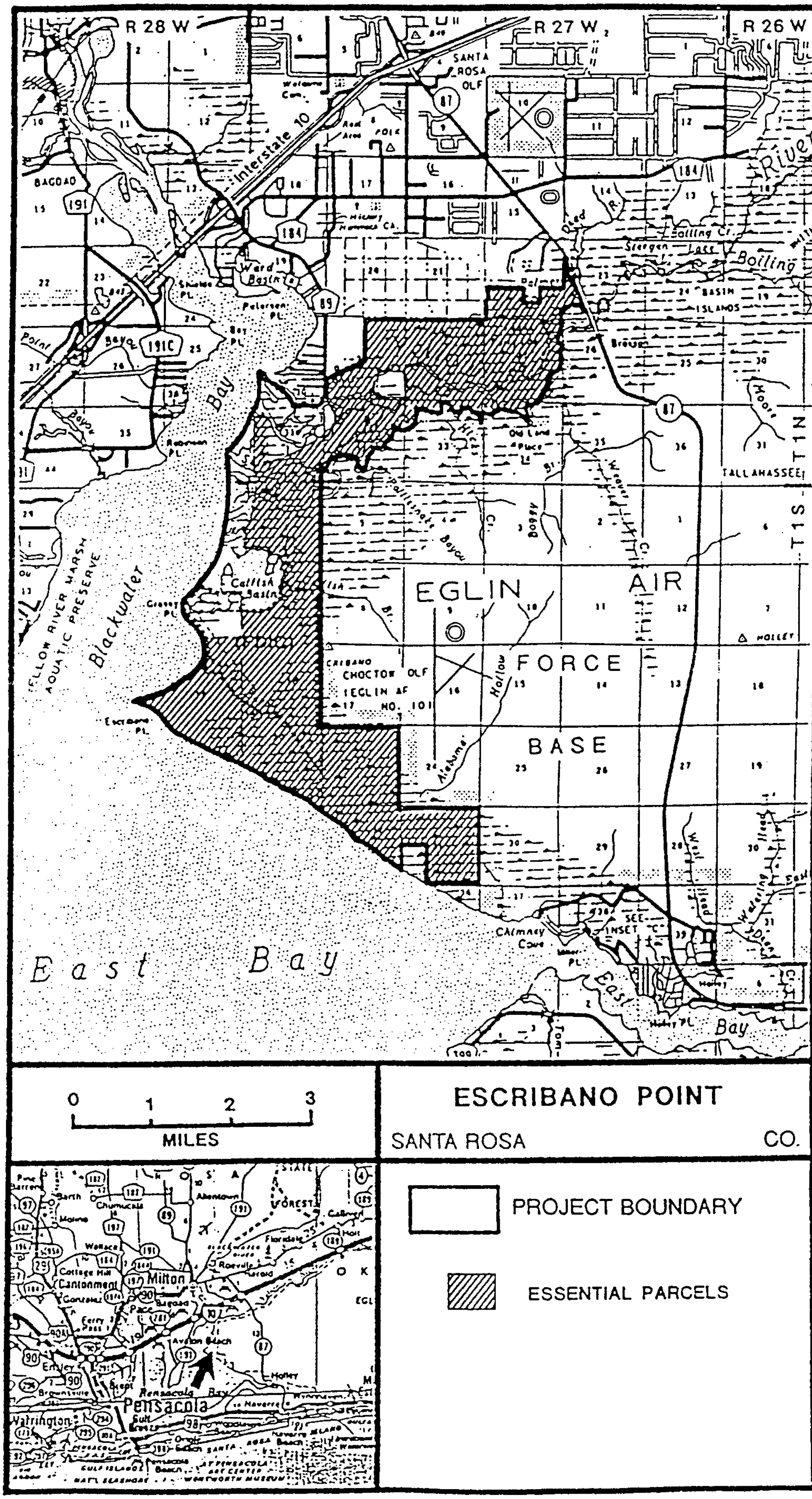
The remnants of a British colo nial home built between 1763 an 1783 have also been found.

Horace Smith, who first settle in the area 40 years ago and lives i a two-story camp he built, said h has no need for running wate power, light or neighbors, though h doesn't mind visitors. He gets by o kerosene lamps, a stove that hook up to a propane tank, and a wel with a hand pump.

"To me it's peaceful," he said. " don't even like to go to the store. just sit down here and listen to th owls howl all night."

Bill Elliott, a Pensacola roofe who visits Smith from time to time hopes Escribano Point stays a "nc man's land."

"Ain't no place you can go anymore to get away from all the people," said Elliott as he sat with Smith under an oak tree with a 21-foot round trunk. "This is a place you come when you want to get away from it all."


R 28 W
R 27 W
R 26 W
SANTA ROSA OLF
Interstate 10
BAGDAD
Ward Basin
Bay
Blackwater
YELLOW RIVER MARSH AQUATIC PRESERVE
Catfish Basin
Escribano Pt.
EGLIN AIR FORCE BASE
CHOCTAW OLF EGLIN AF NO. 101
Boiling
River
Basin Islands
T1N
T1S
TALLAHASSEE
HOLLEY
Chimney Cove
SEE INSET C
East Bay
Holley
0 1 2 3
MILES
ESCRIBANO POINT
SANTA ROSA CO.
PROJECT BOUNDARY
ESSENTIAL PARCELS
Milton
Pace
Bagdad
Pensacola
Cantonment
Gonzalez
Ensley
Brownsville
Warrington
Holley
Navarre
Pensacola Bay
Gulf Breeze
Harold
Allentown
Floridale

Deadhead Logging Permit/Inspection Program
Technical Advisory Committee Final Recommendations

March 27, 2000

Background

Natural woody debris is an important component of healthy river systems, providing critical habitat for fish and invertebrate communities, as well as bank stability and flood velocity attenuation. A Technical Advisory Committee (TAC) was established to recommend the environmental feasibility of removing pre-cut timbers (deadhead logs which were artificially introduced into Florida streams by humans) from state-owned submerged lands. This group consisted of experts in stream habitat and biological communities, hydrology, and Best Management Practices (BMPs). After three meetings, which included a field trip to observe a deadhead logging operation, the TAC concluded that some deadhead logs may be removed with minimal environmental damage if the precautions outlined below are taken.

Overall Strategy

Using OPS (aquatic specialist) environmental inspectors (paid from the use agreement fee), FDEP will conduct a pre-recovery assessment of each permitted river reach, accompanied by the deadhead logger(s). During this assessment, habitat availability, bank stability, boat ramp conditions, etc., will be documented. The deadhead logger will be trained in the practical aspects of environmental protection. After successfully completing training, the logger will be certified as a "Master Deadhead Logger." Additional training will be offered by FDEP as needed.

During the pre-recovery assessment, areas where deadhead recovery is specifically restricted will be mapped and flagged on site. At least one trained "Master Deadhead Logger" will be present during recovery operations. The permittee will be required to inform the FDEP inspectors where and when recovery operations will occur each week (facilitated by a toll-free answering machine and clearly identified FDEP contacts). To determine conformance with the restrictions on deadhead logging identified during the pre-recovery assessment, periodic, random inspections of the recovery operations will be conducted by the FDEP inspectors.

Pre-recovery Assessment

1. Whenever possible, a minimum of two experts on the aquatic system in question should accompany the FDEP inspectors and deadhead loggers during the pre-recovery assessment. Experts include those individuals listed in Attachment A. Due to scheduling difficulties, there may be times that these experts may not be available

to accompany the FDEP inspectors on the pre-recovery assessment, although reasonable steps will be taken to include them.

2. Habitat availability, bank stability, boat ramp conditions, etc., will be photographically documented at each permitted reach. GPS coordinates for each photo will be established for comparison during future inspections.
3. Recovery of deadheads will be prohibited from stream reaches where woody debris is extremely limited, as site-specifically determined during the pre-recovery assessment.
4. No disturbance (pulling, cutting, etc.) of natural snags (woody debris) is allowed during any aspect of deadhead recovery.
5. The presence of vegetated bottoms will be documented. No deadhead recovery is allowed from these areas.
6. Deadhead recovery will not be allowed within 15 feet perpendicular to vertical banks where Rosgen's Bank Erosion Potential (BEP) is >20. Deadhead recovery will not be allowed within 25 feet perpendicular to vertical banks where Rosgen's BEP is >30. Recovery will not be permitted if the pre-cut log is embedded in the stream bank, regardless of the BEP. Restrictions more stringent than these may be noted during the pre-recovery assessment.
7. Recovery will not be allowed from areas that are used for spawning by Gulf sturgeon during the spawning season (March 1 through May 31). Areas used by Gulf sturgeon for spawning include:

   Apalachicola River: Jim Woodruff lock to I-10 bridge
   Choctawhatchee River: Alabama state line to Highway 2 bridge
   Pea River: entire length within Florida
   Suwannee River: Big Shoals to I-10 bridge

8. Consideration of risks to other federal and state endangered and threatened species will be taken into account during the pre-recovery assessment. Information on endangered fish may be found in: Hoehn, T.S. 1998. Rare and imperiled fish species of Florida: A watershed perspective. Office of Environmental Services, Florida Game and Freshwater Fish Commission, Tallahassee. Additional information may be obtained from the Florida Natural Areas Inventory.
9. There will be no recovery allowed from waters adjacent to state parks or state forests or from any river sections where deadhead logging is currently prohibited. However, the Division of Forestry may grant site-specific approval for recovery from state forests.
10. If woody debris is scarce in a stretch of river, the FDEP inspector, during the pre-recovery assessment, may require a minimum number of logs that must remain, either natural or pre-cut.
11. The permittee is required to have a copy of the map showing restrictions present during operations.
12. Areas with poor habitat and bank stability will be documented for potential future state- or federally-sponsored restoration activities.

Education Components

1. No recovery or disturbance of natural woody debris is allowed.
2. Logger will be trained in practical environmental aspects during the pre-recovery assessment.
3. Public access of river and boat ramps will be maintained during deadhead operations.
4. Logs will be pulled and floated, no dragging on bottom allowed.
5. No dredging for logs will be allowed; winching is approved.
6. Private landing for off-loading is preferred, and this location must be communicated to the inspector.
7. BMPs must be used to minimize erosion during off-loading, and restoration activities will occur using appropriate native materials, if needed.
8. If additional authorization for use of boat ramps is needed (certain publicly owned landings), it is the permittee's responsibility to secure permission.
9. No recovery will be allowed when water depths are insufficient to float the recovered timber. In shallow waters where there is a high sediment oxygen demand, recovery is permitted only when temperatures are sufficiently low and water levels are adequate to prevent low dissolved oxygen levels (less than 5 mg/L) from occurring.
10. The logger shall post copies of the permit and use agreement in weather-resistant displays, both upstream and downstream from recovery operations, to inform the public that said operation is authorized.
11. Additional training will be offered by FDEP, as needed.

Random Inspections

1. Each operation shall receive a minimum of one inspection per month.
2. During the pre-recovery assessment, logs that are prohibited from recovery may be marked with a "do not disturb" brand for compliance checking at the off-loading site.
3. Off-loading sites will be randomly inspected for presence of natural woody debris or prohibited logs.
4. Operators failing to abide by the above restrictions shall have their use agreement and permit revoked and/or be fined, depending on the nature or severity of the offense.

Biodiversity Conservation at Multiple Scales: Functional Sites, Landscapes, and Networks

KAREN A. POIANI, BRIAN D. RICHTER, MARK G. ANDERSON, AND HOLLY E. RICHTER

Approaches to conservation and natural resource management are maturing rapidly in response to changing perceptions of biodiversity and ecological systems. In past decades, biodiversity was viewed largely in terms of species richness, and the ecosystems supporting these species were seen as static and predictable (Fiedler et al. 1997). Conservation activities were often aimed at hotspots rich in total species or in rare species (Noss 1987). Consequently, relatively small nature preserves proliferated through the 1970s and 1980s, as did endangered species management and recovery plans on more extensive public lands.

More recently, biodiversity is being viewed more expansively, to include genes, species, populations, communities, ecosystems, and landscapes, with each level of biological organization exhibiting characteristic and complex composition, structure, and function (Noss 1990). As a result, current recommendations for biodiversity conservation focus on the need to conserve dynamic, multiscale ecological patterns and processes that sustain the full complement of biota and their supporting natural systems (e.g., Angermeier and Karr 1994, Turner et al. 1995, Harris et al. 1996, Poff et al. 1997).

Translating expanding perceptions into pragmatic guidelines and appropriate action is a challenge for conservation organizations and natural resource agencies. In this article, we describe an imperfect but practical framework that can help practitioners transition from biodiversity conservation based on rare or endangered species to conservation based on ecosystem- and landscape-level concepts. We begin by providing a brief overview of the scientific concepts from which the framework has evolved. We then describe a convenient way to categorize ecosystems and species based on spatial pattern and scale. Next, we describe three types of "functional conservation areas"—sites, landscapes, and networks—defined by the scale of the ecosystems and species they are designed to conserve. We then present a suite of ecological attributes that can be used to evaluate the functionality or integrity of a conservation area at any scale. Finally, we discuss the challenges of implementing these ideas in applied settings. We illustrate concepts with examples and a case study from the work of The Nature Conservancy (TNC), a nongovernmental organization dedicated to conserving biodiversity throughout the United States and in selected other countries worldwide (TNC 1996).

A FRAMEWORK FOR BIODIVERSITY CONSERVATION BASED ON MAINTAINING FOCAL ECOSYSTEMS, SPECIES, AND SUPPORTING NATURAL PROCESSES WITHIN THEIR NATURAL RANGES OF VARIABILITY

The science of conservation biology

The science of conservation biology has evolved from a crisis-oriented discipline focused on rare or endangered vertebrates to a more proactive experimental discipline focused on patterns and processes at multiple scales. Early on, the technique of population viability analysis was developed to estimate the minimum population size necessary for a particular rare species to persist over time (Ruggiero et al. 1994). Results from these analyses could rarely be validated, and the analyses themselves were information, time, and resource intensive. They quickly illuminated the inefficiency and reductionism inherent in rare- or single-species approaches (Franklin 1993).

Consequently, the single-species approach to conservation quickly broadened to encompass groups of species and certain individual species (e.g., so-called umbrella species, whose habitat requirements are believed to loosely encapsulate an array of additional species; Launer and Murphy 1994). For instance, protecting mammals with large area requirements and diverse habitat needs may

Karen A. Poiani (e-mail: kap4@cornell.edu) is national landscape ecologist for The Nature Conservancy, Department of Natural Resources, Cornell University, Ithaca, NY 14853. Brian D. Richter (e-mail: brichter@theriver.com) is director of the Freshwater Initiative and Holly E. Richter (e-mail: hollyrichter@theriver.com) is restoration ecologist at The Nature Conservancy, Hereford, AZ 85615. Mark G. Anderson (e-mail: manderson@tnc.org) is Eastern regional ecologist for The Nature Conservancy, Boston, MA 02110.

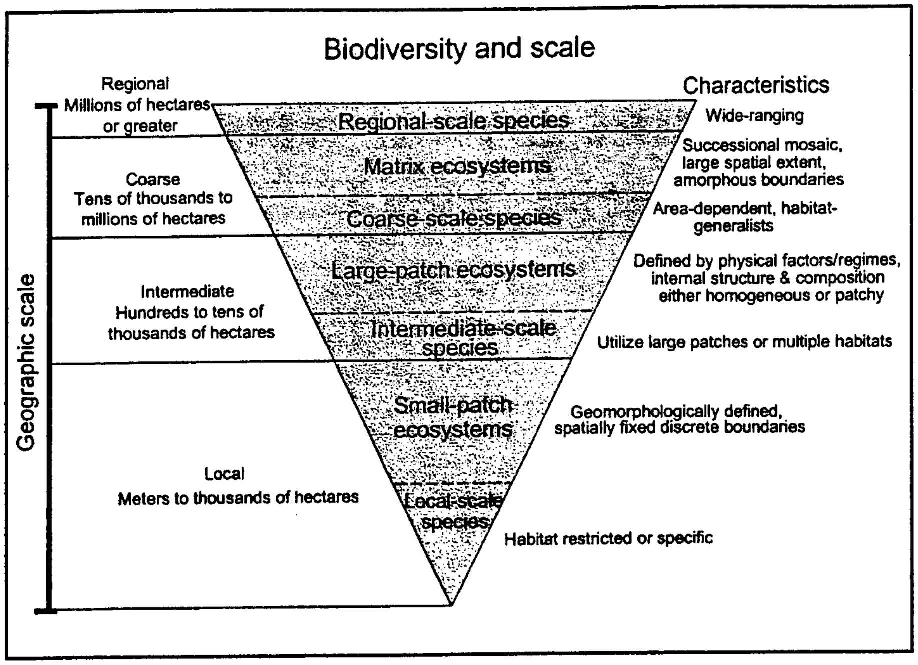


Figure 1. Biodiversity at various spatial scales. Levels of biological organization include ecosystems and species. Ecosystems and species are defined at four geographic scales, including local, intermediate, coarse, and regional. The general range in hectares for each spatial scale is indicated (left of pyramid), as are common characteristics of ecosystems and species at each of the spatial scales (right of pyramid).

protect species with smaller area requirements and more specific habitat needs (Berger 1997). Species guilds—groupings of species based on specific characteristics (e.g., foraging behavior)—is another multispecies approach to conservation and management (Block et al. 1995).

Species guild and umbrella species approaches were a substantial improvement over single-species approaches, but their use in conservation planning still had significant limitations. First, at the site scale, populations of different species typically vary and fluctuate in complicated ways (e.g., one interior forest species may decline while another increases). Second, sites conserved and managed for the needs of a particular species or even a small group of species may fail to conserve other critical components of the ecosystem, including other species or processes that substantially influence the species of concern (Morrison 1986, Block et al. 1987, Landres et al. 1988). Considering that vascular plants and vertebrates together make up less than 10% of known biodiversity, any particular set of species is an extremely small fraction of the biota at any one place (Franklin 1993). Thus, a growing appreciation of the enormous complexity and dynamic nature of ecological systems led to the concept of ecosystem management, wherein success is best assured by conserving and managing the ecosystem as a whole (Christensen et al. 1996).

The shift in focus from species to ecosystems generated new questions. For example, how are ecosystems defined and delineated? How can it be determined whether a particular ecosystem has ecological integrity (i.e., the ability to maintain component species and processes over long time frames)? Ironically, the latter question prompted managers to again assess individual species, but this time as indicators. Indicator species are those used to index or represent environmental conditions, particularly conditions related to ecological degradation (Cairns et al. 1993).

In addition, attempts to unify species- and ecosystem-level concepts in biodiversity conservation prompted the so-called coarse filter–fine filter strategy. This strategy stresses the importance of conserving intact examples of all communities or ecosystems to protect the vast majority of species. Any rare or specialized species that would likely go unprotected under a coarse-level approach are treated individually (i.e., the fine filter; Noss 1987, Hunter 1991).

New ecosystem-oriented paradigms stress that natural systems are vastly complex assemblages of species with elaborate internal and external ecological processes and interactions that help maintain the entire system (Noss et al. 1997). Ecological processes include decomposition, nitrogen cycling, pollination, seed dispersal, energy capture, food webs, insect outbreaks, disease, herbivory, and predation. Some species—including top-level carnivores (Paine 1974), dominant herbivores (Naiman 1988), and builders such as beaver, prairie dog, or gopher tortoise (Perry 1994)—may be disproportionately important in maintaining these critical processes, and the removal of such "keystone" species may have a cascade effect on other species and processes.

Another important concept that has emerged in conservation biology and ecology over the last several decades is that of the metapopulation—a group of subpopulations linked together by dispersal of individuals and gene flow. Metapopulations are often characterized by sources and sinks. Sources consist of suitable or optimal habitat and generally produce excess individuals, and sinks are composed of unsuitable habitat, in which population size cannot be maintained without immigration from source areas. Pulliam (1988) demonstrated that as little as 10% of a population may be located in source habitats and still be responsible for maintaining 90% of the population found in sink habitats.

Biodiversity and spatial scale

Scientists and practitioners have long recognized that biodiversity exists at many levels of biological organization,

from genes to landscapes (Noss 1990, Angermeier and Karr 1994). In this article, we focus on two levels of biological organization: ecosystems and species (we assume that focusing efforts at these levels will also conserve genetic- and landscape-level diversity). We define ecosystems as dynamic assemblages or complexes of plant and/or animal species (including vascular and nonvascular plants, vertebrates, invertebrates, fungi, and microorganisms) that occur together on the landscape; that are linked by similar ecological processes (e.g., fire, hydrology), underlying environmental features (e.g., soils, geology), or environmental gradients (e.g., elevation); and that form a cohesive and distinguishable unit.

Biodiversity also occurs at a variety of spatial or geographic scales. Our framework distinguishes ecosystems and species at four geographic scales: local, intermediate, coarse, and regional. Species in the framework occur at all four spatial scales (Figure 1). Ecosystems occur at three of the four scales and are described in relation to their spatial patterning (i.e., small-patch ecosystems at the local scale, large-patch ecosystems at the intermediate scale, matrix ecosystems at the coarse scale; Figure 1). Specific conservation areas generally contain ecosystems and species at multiple spatial scales that nest together in complex configurations.

Local geographic scale. Both small-patch ecosystems and local-scale species exist at a local geographic scale (i.e., meters to thousands of hectares). Local-scale species are restricted to a particular habitat, are immobile or poor dispersers, and include many species of invertebrates and plants. For example, the Bay checkerspot butterfly (*Euphydryas editha bayensis*) is a relatively poor disperser that is restricted to serpentine grasslands in California (Murphy and Weiss 1988). Small-patch ecosystems tend to be relatively discrete, geomorphologically defined, and spatially fixed; they often occur because of distinct abiotic factors (e.g., geologic outcrops, unique soils, or hydrologic features, such as seeps). Local-scale species are usually closely connected with specific small-patch ecosystems. Typical examples of small-patch ecosystems in an eastern deciduous forest landscape include calcareous fens, acidic bogs, and high-elevation rocky summits (Anderson et al. 1998). Examples in the western United States include cienega wetlands, desert spring pools, serpentine grasslands, and fern grottos supported on cliff faces by groundwater seeps.

Intermediate geographic scale. Both large-patch ecosystems and intermediate-scale species exist at an intermediate geographic scale (i.e., hundreds to tens of thousands of hectares). Large-patch ecosystems are relatively discrete, defined by distinct physical factors and environmental regimes, and are significantly larger than small-patch ecosystems. Some large-patch ecosystems—such as red maple swamps, coastal salt marshes, and redwood forests—are defined by relatively stable physical factors and tend to be fairly uniform in internal composition and structure. Other large-patch types, such as western riparian ecosystems, northeastern pine barrens, prairie savanna mosaics, and aquatic macrohabitats in rivers, are defined by dynamic and more frequent disturbance regimes. These large-patch ecosystems are variable in structure and composition, with distinctly different internal habitat types and seral stages that shift and rearrange over time and space. We refer to these dynamic habitat types and seral stages within large-patch ecosystems as "patch types." Small- and large-patch ecosystems commonly make up the majority of coarse-filter diversity in any given region.

Intermediate-scale species depend on large-patch ecosystems or on multiple habitats. For example, a floodplain-spawning fish uses the main channel, floodplain backwaters, and sloughs of aquatic ecosystems. Another example is decurrent false aster (*Boltonia decurrens*), an imperiled floodplain plant that occurs only along the Illinois River and at its confluence with the Mississippi River. *B. decurrens* depends entirely on a dynamic large-patch floodplain ecosystem and germinates on exposed mudflats created by spring floods (Smith et al. 1993). Even though *B. decurrens* inhabits a single patch type (exposed mudflats), we consider it an intermediate-scale species because this habitat is part of a large-patch riparian mosaic.

Coarse geographic scale. Matrix ecosystems and coarse-scale species occur at geographic scales of tens of thousands to millions of hectares. Terrestrial ecosystems at this scale include the dominant (or historically dominant) matrix-forming vegetation in which large- and small-patch ecosystems are embedded. In the Northeast, matrix ecosystems consist of spruce–fir forests, northern hardwood forests, and their successional stages (Anderson et al. 1998). In the southeastern Atlantic Coastal Plain, longleaf pine (*Pinus palustris*) forests historically dominated a vast portion of the landscape. In the West, various types of sagebrush scrub (*Artemisia* spp.) and grasslands form an extensive matrix in low-elevation intermountain areas. Matrix ecosystems are nondiscrete in their boundaries and are defined by general, widespread climatic and elevation gradients.

Species at the coarse scale are habitat generalists, moving among and using ecosystems at multiple scales. Greater prairie chickens (*Tympanuchus cupido pinnatus*) of the central Great Plains are a coarse-scale, area-dependent species. They depend on large areas of the historic grassland matrix, a mix of small wetlands and shrublands, and readily use various agricultural lands (Merrill et al. 1999).

Regional geographic scale. Regional-scale species exist at the broadest geographic scale; they include wide-ranging animals, such as migrating ungulates and top-level predators. These species use resources over millions of

hectares or more, including natural to semi-natural matrix and embedded large- and small-patch ecosystems. Examples include caribou (*Rangifer tarandus*) of northern North America, mountain lions (*Puma concolor*) in the West, jaguar (*Panthera onca*) in Latin America, American bison (*Bison bison*) of the Great Plains, migratory fishes in big rivers, and many species of migratory birds.

The exact geographic scale of a particular ecosystem or species in a given area or region will depend on several factors, including the environmental setting and the species' life-history characteristics. Some regions, such as the North American Great Plains and the southeastern Coastal Plain, are characterized by flat topography and large-scale disturbance regimes (e.g., landscape fires, hurricanes). Natural matrix ecosystems in these areas (e.g., tallgrass prairie, longleaf pine forests) originally occurred over millions of hectares. In contrast, steep topography and more localized disturbance regimes (e.g., ridgetop fires, landslides, ice storms) in the southern Blue Ridge Mountains have produced a patchwork vegetation pattern. Matrix ecosystems in this latter region may be an order of magnitude smaller than in the Great Plains or Coastal Plain. Moreover, an animal species may use resources at different scales in different regions (e.g., mountain lions may be regional-scale species in one region and coarse-scale species in another). Consequently, it may be difficult to assign an ecosystem or species to an exact scale, particularly because basic, region-specific life-history information is lacking for most species. Thus, we define the extent of the four geographic scales generally and with overlapping values to account for these regional differences.

Functional conservation areas—sites, landscapes, and networks

Conservation of biodiversity at multiple levels of biological organization and spatial scales is complex and requires two key steps: explicit identification and protection of the focal ecosystems and species in a given area, and adequate identification and protection of the associated multiscale ecological processes that support and sustain those ecosystems and species (Pickett et al. 1992, Meyer 1997). These requirements are met within what we call functional conservation areas. We define a functional conservation area as a geographic domain that maintains focal ecosystems, species, and supporting ecological processes within their natural ranges of variability.

Functional conservation areas have several characteristics. First, the size, configuration, and other design characteristics will be determined by the focal ecosystems, species, and supporting ecological processes. Second, a conservation area is functional if it maintains the focal biotic and abiotic patterns and processes within their natural ranges of variability over time frames relevant to conservation planning and management (e.g., 100–500 years). Third, functional conservation areas do not necessarily preclude human activities, although their functionality or integrity may be greatly influenced by such activities (Redford and Richter 1999). Finally, functional conservation areas at all scales may require ecological management or restoration to maintain their functionality (e.g., prescribed burning, invasive species removal).

We define three types of functional conservation areas sites, landscapes, and networks (Figure 2). The defining characteristics of these conservation areas are the ecosystems and species they are designed to conserve. Functional sites aim to conserve a small number of ecosystems and/or species within their natural ranges of variability at one or two scales below regional; functional landscapes seek to conserve many ecosystems and species within their natural ranges of variability at all scales below regional (i.e., coarse, intermediate, and local); and functional networks are integrated sets of sites and landscapes designed to conserve regional-scale species within their natural ranges of variability.

Examples of functional sites are areas intended to conserve one or more rare or endangered species or uncommon ecosystems, often at the local scale. Such areas constitute the majority of nature preserves in the United States. These areas are functional sites if they adequately conserve (or restore through management) the focal biodiversity and their sustaining ecological processes (e.g., fire, flood, dispersal, pollination) within their natural ranges of variability (Poiani et al. 1998). Although ecosystems and species of concern at functional sites are not necessarily easy to conserve, they are relatively few and easy to identify, and they share similar sustaining ecological processes (e.g., an assemblage of fire-dependent prairie plants and butterflies, or a wetland complex and its associated rare species). In some cases, and especially over the long term, functional sites for even small-patch ecosystems and local-scale species may require large areas to be conserved.

In functional landscapes, ecosystems and species of conservation concern are more numerous than at functional sites. Functional landscapes typically encompass the full terrestrial to aquatic (and sometimes marine) gradient, and they require a diversity of sustaining ecological processes. Functional landscapes usually exist within a human- or multiple-use context and commonly span diverse land ownership.

It is the degree to which an area comprehensively conserves biodiversity at three or more scales, rather than its size, that distinguishes a functional landscape from a functional site. Indeed, the size of a conservation area alone does not ensure the protection of biodiversity at all scales (Simberloff 1998). For example, conservation areas in the southeastern Coastal Plain that seek to conserve coarse-scale red-cockaded woodpeckers (*Picoides borealis*) must encompass extensive expanses of longleaf pine matrix with significant old growth and sparse understory (Hardesty et al. 1997). Woodpecker conservation therefore requires protection and fire management of large areas. Yet

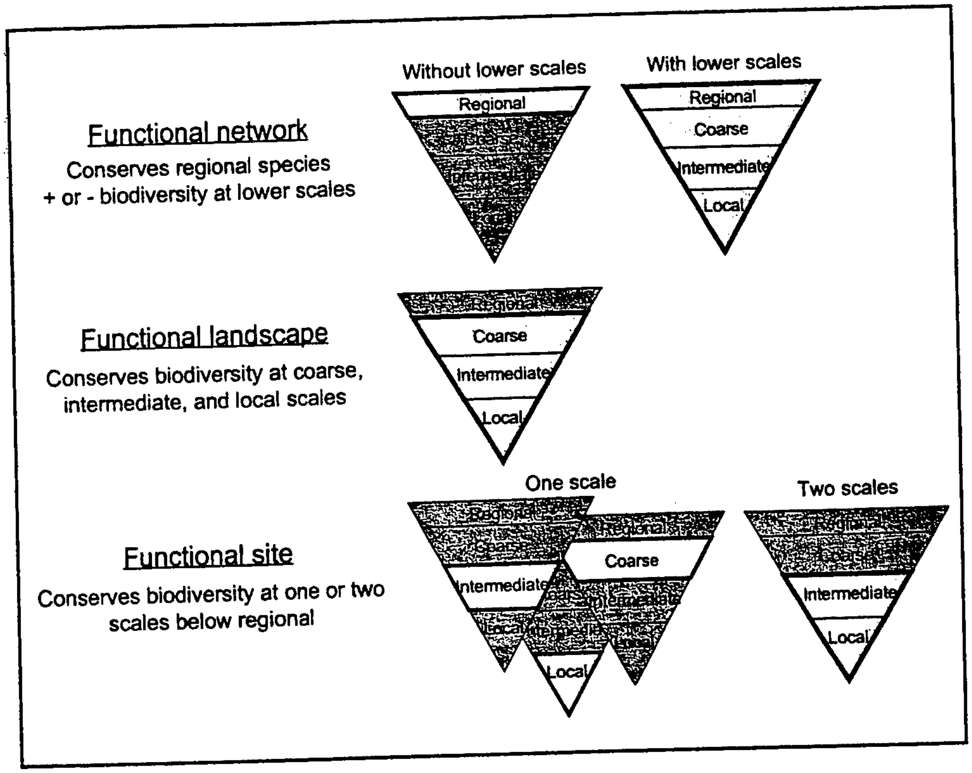


Figure 2. Definitions of functional sites, landscapes, and networks and their relationships to biodiversity at various spatial scales.

it is possible to conserve woodpeckers and their required habitat and still degrade nonfocal biodiversity (e.g., streams and wetlands and their associated species). Similarly, a functional site focused on intermediate-scale aquatic species might require attention to large watershed areas because of the need to maintain natural hydrologic and water chemistry regimes. Again, full protection of the habitat and ecological processes that sustain aquatic species may not be enough to conserve terrestrial biodiversity, such as upland rare plants, matrix forest, or forest interior birds.

Finally, functional networks provide adequate spatial context, configuration, and connectivity to conserve regional-scale species with or without explicit consideration of biodiversity at finer scales. Sites or landscapes within functional networks can be arranged contiguously within one region or in several adjacent regions to protect species such as migrating ungulates or grizzly bears (*Ursus arctos horribilis*). Conversely, sites or landscapes may form a series of stepping stones spread over many regions to protect migratory species, such as certain birds, insects, and bats.

Although functional networks are intended to conserve regional-scale species, some functional networks may also include explicit attention to biodiversity at other scales. Functional networks with a multiscale perspective differ fundamentally from networks focused solely on regional-scale species. Examples of networks focused on regional-scale species alone have been articulated for several areas of the United States (e.g., Noss 1993, Cox et al. 1994); such designs do not explicitly consider the area or actions necessary to conserve finer-scale ecosystems and species within these regions. Functional networks that continue to conserve both regional-scale species and biodiversity at all finer scales include the Brooks Range of Alaska, the northern Rocky Mountains in the United States and Canada, and the Serengeti–Mara system in Tanzania and Kenya.

Conservation at multiple scales

Implementing a functional conservation approach requires practitioners to first identify the ecosystems or species toward which conservation efforts are or will be directed. Conservation organizations and natural resource agencies should strive for a comprehensive, multiscale approach, in which they direct conservation efforts toward biodiversity at the coarsest scale an area can support and then determine the extent to which ecosystems and species at finer scales can be targeted. Thus, new conservation areas should, wherever possible, be functional landscapes or contribute to a functional network. If an area cannot support a functional landscape or regional-scale species, a functional site should be delineated and conserved at the highest possible scale.

Determining the appropriate focus for a conservation area is an iterative process, in which initial assumptions about site or landscape functionality are examined more rigorously over time. Periodic refinement of the initial focus is warranted following management, research, or other ongoing observations. For example, areas designed to conserve one or a few local- to intermediate-scale ecosystems or species may be logically extended to include coarser patterns (e.g., a site focused on a large-patch riparian mosaic may be expanded to conserve adjacent high-quality upland matrix), whereas an area that is designed with a coarse-scale focus may, in light of new findings, need to be refocused downward to include finer-scale patterns (e.g., a site focused on red-cockaded woodpeckers may need to be expanded to conserve high-quality small-patch wetlands and their associated local-scale species).

Directing conservation efforts toward biodiversity at coarse scales while integrating ecosystems and species at finer scales has many benefits. Attention to coarse-scale ecosystems—particularly outright conservation of matrix types—has generally been neglected by private conserva-

tion efforts. Matrix ecosystems are relatively common and typically do not contain many rare species (Franklin 1993). However, an intact matrix is often key to the long-term persistence of large- and small-patch ecosystems and lower-scale species.

Multiscale conservation can also offer a more comprehensive and conservative strategy for protecting little-known species and genetic diversity, especially if conservation areas encompass broad physical and biological gradients and capture unique environmental features (Hunter et al. 1988). Such comprehensive gradients offer greater protection against and capacity to accommodate human-induced environmental change (e.g., climate change, acid deposition, invasive species; Hunter et al. 1988). However, understanding and monitoring complex multiscale conservation areas will often require substantial resources.

Functional networks should also, to the extent that it is scientifically sound, seek to conserve ecosystems and species at finer scales. Conserving species at a single scale (even an umbrella species at the coarse or regional scale) can miss important linkages, ecological processes, and biodiversity at other scales (Simberloff 1998).

Ecological attributes for evaluating functionality

Identifying and protecting functional conservation areas is challenging, given the complexity of both ecological and human issues at any given place (Stanford and Poole 1996). One of the most important but difficult tasks in the process is to determine a conservation area's degree of functionality or ecological integrity. Such information is critical in formulating appropriate conservation, management, and restoration strategies and in evaluating current and potential human uses. Assessment of ecological integrity or functionality is a relatively undeveloped area in applied ecology. Although almost all natural systems and species are influenced by a multitude of past and current human activities (Breitburg et al. 1998), the effects of these activities on biodiversity are often complex and sometimes obscure. Thus, assessing an area's functionality should be an iterative process based on accumulated knowledge.

The list of potential attributes that can be examined to assess a conservation area's functionality or integrity is exceedingly long (e.g., Noss 1990). Applied conservation organizations rarely have the ability and resources to examine all of them. Based on our experiences at many conservation sites and landscapes, we suggest evaluating four well-known attributes (which encompass the critical patterns and processes at most conservation areas). Ideally, other area-specific attributes could be added as time and resources allow (e.g., Hardesty et al. 1997). The four attributes are composition and structure of the focal ecosystems and species; dominant environmental regimes, including natural disturbance; minimum dynamic area; and connectivity.

Evaluating these attributes at functional sites and even functional networks should be relatively straightforward. However, evaluating the attributes for functional landscapes is more challenging. To assess functional landscapes, a subset of ecosystems and species must be selected that adequately identifies the patterns and processes needed to conserve the entire functional landscape (i.e., for planning) and that provides information on landscape functionality over time (i.e., for adaptive management and monitoring). Focal ecosystems and species selected for these two purposes may not necessarily be the same. In both cases, however, it is important to choose ecosystems and species at all focal spatial scales (e.g., Hansen and Urban 1992, Block et al. 1995, Hardesty et al. 1997, Breininger et al. 1998). Exemplary focal ecosystems and species for functional landscape planning and monitoring include those that require specific management or conservation strategies, those that integrate or span various parts of the terrestrial–aquatic gradient (e.g., species that use wetlands and uplands), those that are known to be sensitive to alterations in the key attributes (i.e., indicator species), those that play a primary role in sustaining key ecological processes (i.e., keystone species), and those that are readily monitored. For nongovernmental conservation organizations, a focus on endangered species will also provide a good link to the mission of state and federal agency partners. Several guidelines provide further insights for defining and selecting indicator, focal, and keystone species (e.g., Noss 1990, Cairns et al. 1993, Noss and Cooperrider 1994, Power et al. 1996, Noon et al. 1997, Simberloff 1998).

Composition and structure. For purposes of biodiversity conservation, functionality or integrity of a conservation area can perhaps best be judged by the extent to which the composition and structure of the focal ecosystems and species are within their natural ranges of variability. Even for conservation areas with intact or nearly intact ecological processes, conservationists should not assume that focal ecosystems and species are compositionally and structurally intact. For example, invasive non-native species can displace natives, completely altering ecosystem composition, while general ecological processes such as fire and flood are still maintained. In addition, preliminary evidence shows that compositional and structural integrity may be critical in maintaining internal stability, productivity, and resilience of the ecosystem itself (e.g., Johnson et al. 1996, Naeem 1998).

Key compositional and structural components for species are age structure, evidence of reproduction, population size or abundance, and, when possible, genetic diversity and minimum viable populations. Key compositional and structural components for ecosystems are more complex and can include abundance of invasive species (non-native or native), presence of keystone species, presence of species that indicate unaltered ecological process-

es, abundance of important prey species, existence of characteristic species diversity, evidence of reproduction of dominant species, and evidence of vertical strata or layering. Composition and structure of focal large-patch and matrix ecosystems can also include the spatial distribution and juxtaposition of internal patch types or seral stages, the presence of characteristic patch types, and the extent of fragmentation and non-natural or semi-natural land uses.

Dominant environmental regimes. To determine the functional status of a conservation area, practitioners must understand and evaluate dominant and sustaining environmental regimes relative to the ecosystems and species of concern. Environmental regimes can be diverse and can vary considerably among conservation areas. Important dominant environmental regimes include grazing or herbivory, hydrologic and water chemistry regimes (surface and groundwater), geomorphic processes, climatic regimes (temperature and precipitation), fire regimes, and many kinds of natural disturbance.

Natural disturbance can be defined as "any relatively discrete event in time that disrupts ecosystem, community, or population structure and changes resources, substrate availability, or the physical environment" (White and Pickett 1985). Natural disturbance is a key aspect of environmental regimes and plays a critical role in the dynamic fluctuation of habitat availability and biotic diversity. When environmental regimes and natural disturbances are pushed outside their natural ranges of variability by human influences, changes in ecosystems and species will follow.

There are few places where completely unaltered environmental regimes and natural disturbances currently exist, particularly those operating at broad scales. For example, Alaska and northern Canada may be the only remaining areas in North America that have truly natural fire regimes. Even Yellowstone National Park, where most lightning fires are allowed to burn, does not have a completely natural fire regime (Romme and Despain 1989). Thus, it is critical to evaluate the potential to restore regimes and disturbances through active management (e.g., prescribed fire, prescribed floods, managed grazing).

Minimum dynamic area. Another consideration in assessing functionality of sites, landscapes, and networks is their necessary size or extent. Dynamic natural disturbances may greatly influence local populations and ecosystems, even causing their local extirpation. Within large-patch and matrix ecosystems, disturbances create a diverse, shifting mosaic of successional stages and physical settings of different origin and size (Bormann and Likens 1979). Although many small-patch ecosystems tend to be more stable in their location, disturbances also influence their composition and structure, and populations of species within them can fluctuate widely. Thus, metapopulation spatial structure and processes may be essential to sustain local-scale species and small-patch ecosystems, for which replication and connectedness would be more important than size (Fahrig and Merriam 1985).

Regardless of whether a shifting mosaic or metapopulation model is most appropriate, the rate of recovery of an ecosystem or species at any scale following disturbance is influenced strongly by the availability of nearby organisms or propagules and biological "legacies" (e.g., seed banks, underground biomass) for recolonization (Holling 1973). When recolonization sources are available and plentiful, recovery will be optimal. The area needed to ensure survival or recolonization has been called the minimum dynamic area (Pickett and Thompson 1978). For certain small-patch ecosystems and species, this concept may be better described as "minimum dynamic number."

Minimum dynamic area has already become an important consideration in the design of conservation areas and should be a primary factor in assessing functional sites, landscapes, and networks. For example, Shugart and West (1981) suggested that, as a rule of thumb for forested ecosystems, the minimum dynamic area is typically 50 times the mean disturbance patch size. Baker (1992) emphasized that reserves should be large relative to maximum disturbance sizes, thus minimizing their vulnerability to catastrophic loss of organisms, reducing the chance of disturbance spreading to adjacent developed lands, and minimizing the influences of adjacent lands on the size and spread of disturbance at the margins. In addition, Peters et al. (1997) suggested that a minimum dynamic area must be large where disturbance events are either large or common. They recommended that managers use simulation models to analyze system response to natural disturbances and to determine the minimal area needed to absorb the largest disturbance event expected within a 500–1000-year period. Developing scientific estimates of minimum dynamic area and metapopulation structure for biodiversity at different scales, or guidelines as to how to develop such estimates efficiently, is one of the critical frontiers of applied conservation biology.

As well as considering natural disturbance regimes, it may also be critical to estimate the minimum conservation area needed to actively manage for broad-scale disturbances, in cases where disturbance regimes will never be fully intact. For example, many sites need to be large enough to burn or graze on a rotational basis and to satisfy a variety of species and habitat requirements (Biondini et al. 1999).

Connectivity. Connectivity includes several key concepts: focal species have access to all habitat and resources needed for life cycle completion, focal ecosystems and species have the ability to recover following disturbance, and focal ecosystems and species have the ability to respond to environmental change (Saunders et al. 1991, Stanford and Ward 1992, Rosenberg et al. 1997). For example, access to backwater areas on a floodplain during

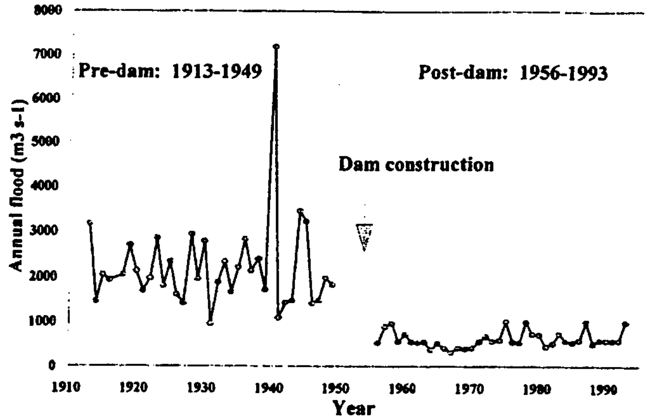


Figure 3. Hydrograph of annual flood levels (m^3/s) for the Roanoke River, North Carolina, shows changes in natural flow regime. Large dams began operating on the Roanoke River in 1956.

annual spring floods may be critical for fish spawning (Sedell et al. 1990). Enabling local- to regional-scale migrations of various ecosystems and species will become critical with global warming. Functional conservation areas must allow for such movements by encompassing entire elevational gradients or spanning many geological substrates, depending on the needs of the focal systems and species (Hunter et al. 1988). For example, to fully conserve vernal pools over a 100-year time frame, it may be necessary to protect pools that vary in size, depth, hydroperiod, and substrate, such that component species have the natural abiotic template on which to evolve over time.

The degree to which a site, landscape, or network is connected and the ability of organisms to move, disperse, migrate, or recolonize varies with the species (e.g., Hansen and Urban 1992, Pearson et al. 1996). A landscape that is fragmented to a black bear, for example, may be continuous to a local-scale insect (Wiens and Milne 1989). Thus, connectivity must be considered in light of the wide range of life-history characteristics and ecological processes of the focal biodiversity. This situation reiterates the importance of selecting focal biodiversity at multiple scales for complex functional landscapes.

A word on natural ranges of variability. Ecological patterns and processes as described above are highly dynamic in time and space (Morgan et al. 1994). To protect focal biodiversity over long time frames, practitioners need to understand, describe, and, where possible, quantify and conserve the range of these natural biotic and abiotic fluctuations (Noss 1985, Swanson et al. 1993, Poff et al. 1997, Richter et al. 1997). For example, flood disturbances have been suppressed in the majority of rivers in the Northern Hemisphere (e.g., Figure 3). When a key disturbance regime such as flooding is pushed outside (typically below) its natural range of variation, ecosystems and species that depend on conditions associated with large floods may not be viable over the long term (Poff et al. 1997).

Unfortunately, present understanding of most biotic and abiotic variation and its causes is rudimentary. Biological monitoring data are limited and often inadequate for describing long-term variation. Data sets from long term research sites (Bildstein and Brisbin 1990) and breeding bird surveys are several significant exceptions. Furthermore, for most locations in the United States, historical records exist that at least allow researchers to reconstruct or characterize environmental regimes, such as stream flow, temperature, and precipitation.

In addition, a variety of methods have proven useful for reconstructing presettlement or historic patterns and processes to help define natural ranges of variability (Noss 1985, Morgan et al. 1994, Birks 1996, Delcourt and Delcourt 1996, Poiani et al. 1996, Foster et al. 1998). These methods include simulation modeling, historical accounts and early land surveys, interpretation of historic aerial photographs, and paleoecological evaluations of sediments, charcoal, tree rings, pollen, and seed banks. Thermographs, rainfall hyetographs, hydrographs (e.g., Figure 3), or output from simulation models can be summarized statistically (e.g., magnitude, intensity, duration, timing, frequency, spatial extent, and rate of change) to describe and quantify natural ranges of variability (Baker 1992, Morgan et al. 1994, Richter et al. 1996). Also, when data are not available for a particular ecosystem or species, deductions about cause-and-effect relationships can sometimes be drawn from reference areas or similar ecosystems and organisms (Arcese and Sinclair 1997).

Ecological models (particularly simulation models) can aid in assessing acceptable variability in focal patterns and processes (e.g., Lauenroth et al. 1998, Maddox et al. 1999). When human land and water use regularly push key environmental parameters outside their natural ranges, or threaten to do so in the future, a predictive model can provide a potent tool for understanding possible consequences for focal biodiversity. Simple rule-based state-and-transition models are particularly useful for understanding vegetation dynamics (e.g., Poiani and Johnson 1993, Johnson 1994, Ellison and Bedford 1995, Richter 1999). Population dynamics models can also predict the cumulative effect of repeated perturbation on focal species (Ruggiero et al. 1994, Noon et al. 1997).

The challenges of implementation

The overall framework outlined in this article may be most useful if employed several times during the course of ongoing conservation activities. As a first step, ecological attributes can be rapidly evaluated to identify focal ecosystems and species for a new or existing conservation area. As a second step, ecological attributes must be evaluated in greater depth and detail during ongoing planning and adaptive management to examine and refine the initial assumptions. Evaluating the attributes using data, simula-

tion models, historical analyses, or monitoring and research projects may be appropriate during this second stage.

Evaluation of both ecological patterns and processes, however, represents a major challenge for conservation scientists and practitioners. Among the greatest problems is translating the four functional attributes into effective, useful, and measurable specifics for planning, monitoring, and assessment. For example, are there rules of thumb for determining minimum dynamic area for various ecosystem types? Do thresholds exist for environmental regimes (e.g., flooding), fragmentation, or invasive species beyond which ecological integrity is diminished to unacceptable limits? In addition, identifying a subset of focal ecosystems or species (i.e., indicators, keystones, or guilds) that may be used to gauge broader site or landscape functionality is proving difficult (Landres et al. 1988). Even focusing on keystone species appears to miss many vital components of an ecosystem (Franklin 1993), although further research may reveal more promising results (Simberloff 1998).

In the human arena, implementing conservation across multiple scales requires unprecedented levels of coordination among federal, state, and local institutions, both public and private. Many small-patch ecosystems and local-scale species can still be approached in a site-based fashion using the traditional strategies of land purchasing or easements. However, effective conservation at a local scale is generally management intensive and may be the most expensive option in the long run. Conserving functional landscapes, by contrast, typically requires greater initial investments and extensive partnership networks, including a diverse cast of stakeholders. At the scale of the functional network, evaluation of existing managed areas, regionwide threats, public input, zoning, and education become essential tools, again requiring extensive coordination and cooperation among landowners.

A TNC case study illustrates the application of the framework described in this article. Drawing from our 14 years of experience along the Yampa River in northwestern Colorado, we describe the challenges and benefits derived from a multiscale, functional conservation approach.

The Yampa River case study

The Yampa River originates along the continental divide of the Rocky Mountains in northwestern Colorado at an elevation of approximately 3400 meters above sea level and flows 300 km to join the Green River near the Utah border. The upper tributaries in the watershed are small, steep-gradient montane streams that are generally 1–4 m wide. These tributaries coalesce to form the 30–40 m wide mainstem of the river, which runs through broad, gently sloping valleys and, occasionally, narrow canyons. As the river flows west, it crosses from the Colorado Rocky Mountains, which are dominated by coniferous forests, aspen stands, and montane shrublands, to the Wyoming Basin region, which is dominated by Wyoming big sagebrush (*Artemisia tridentata* ssp. *wyomingensis*). Along the longitudinal gradient of the river and its tributaries, the riparian vegetation varies greatly. Average annual precipitation in the headwaters exceeds 150 cm per year, most of which falls as snow, resulting in a snowmelt-driven flood regime. Flows in the mainstem peak in late May to early June, ranging from an average low of 14–28 m^3/s to an average high of 140–280 m^3/s.

Conservation focus. TNC's work along the Yampa River over the past 14 years illustrates the evolution from conservation focused on rare biodiversity to the design and management of a functional conservation area. Between 1986 and 1996, TNC acquired several hundred acres along the Yampa River, primarily to conserve mature stands of the globally rare box elder–narrowleaf cottonwood/red-osier dogwood (*Acer negundo–Populus angustifolia/Cornus sericea*) riparian forest. In the mid-1990s, TNC developed a conceptual ecological model that would provide a broad framework for understanding the dynamics of the riparian system along the mainstem of the Yampa River. The model quickly revealed that the globally rare forest TNC initially sought to protect was in fact only one of several shifting patch types within a larger dynamic riparian ecosystem (Figure 4). That is, the rare forest type was not a stable, small-patch ecosystem that could be managed out of context from the overall large-patch riparian mosaic. Thus, TNC's conservation focus evolved from protecting a single riparian patch type at a local scale to protecting the entire large-patch riparian mosaic at an intermediate scale.

A second expansion in scale? More recent discussions of Yampa River conservation center around whether focus should shift again, from a functional site aimed at the large-patch riparian mosaic and associated fine- and intermediate-scale species to a functional landscape that seeks to conserve biodiversity at all scales. Matrix ecosystems surrounding the Yampa River at both high and low elevations remain relatively unaltered. For example, the USDA Forest Service manages the majority of the upper watershed as part of the Routt National Forest. A greater percentage of private ownership exists lower in the basin, but much of the Wyoming big sagebrush matrix in this area remains relatively intact. In addition, several important coarse-scale species appear to be supported by the sagebrush matrix and other embedded patch ecosystems within the watershed, including elk (*Cervus elaphus*) and Columbian sharp-tailed grouse (*Tympanuchus phasianellus columbianus*). The latter species is declining over much of its range due to the loss, degradation, and fragmentation of sagebrush habitat throughout the West. However, the northwestern Colorado population of sharp-tailed grouse is the largest within the state and apparently stable, and it may represent an important conservation opportunity (Giesen and Braun 1993).

The Yampa River watershed may also provide one of the

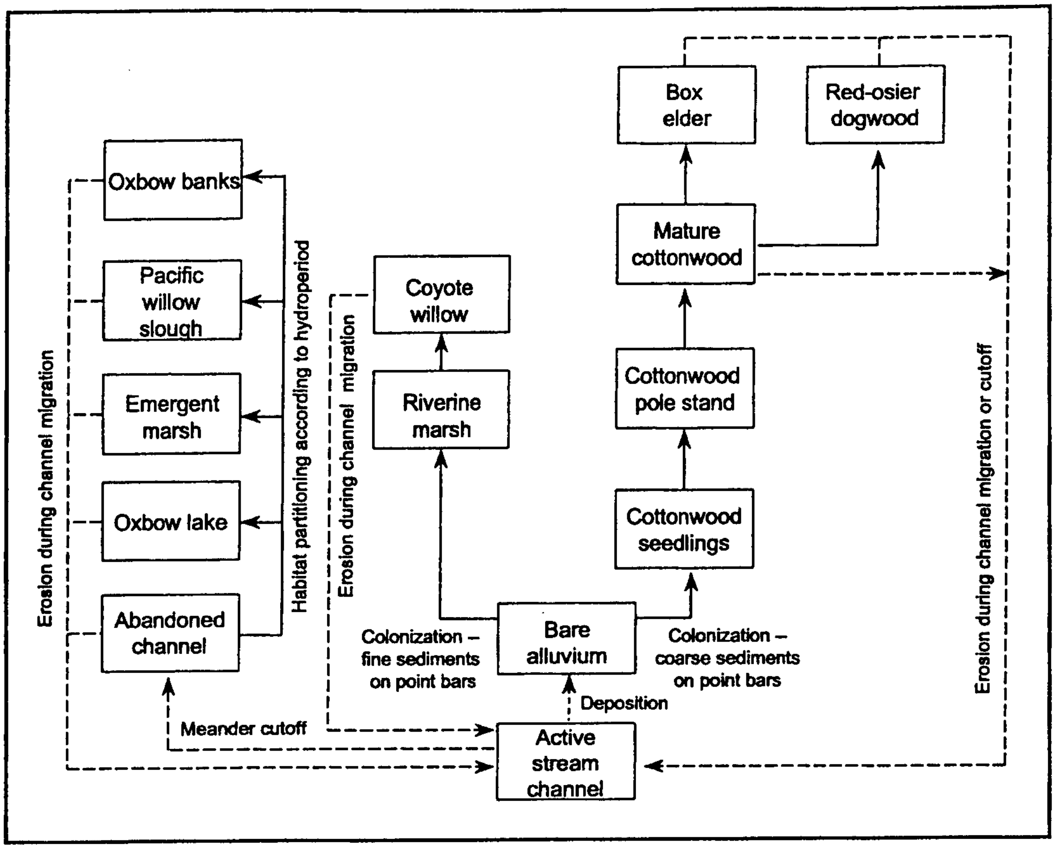


Figure 4. Conceptual ecological model of riparian patch dynamics along the Yampa River, Colorado. Boxes indicate the various patch types within the riparian mosaic, solid arrows indicate biotic succession, and dashed arrows represent geomorphic changes. Figure reprinted from Richter (1999).

necessary functional landscapes for regional-scale species in the area. Bald eagles (*Haliaeetus leucocephalus*) nest along the Yampa River during the summer, several hundred greater sandhill cranes (*Grus canadensis tabida*) use the valley as a critical staging area during their spring and fall migrations, and many neotropical migratory birds nest and forage within the riparian corridor. Adequate protection of such regional-scale species obviously requires more than just the Yampa River watershed. However, TNC biologists may need to explicitly consider these regional-scale species in their conservation and management efforts. Further information is needed before the conservation effort at Yampa River can undergo a second expansion in scope, but such issues illustrate the multiscale, iterative process we advocate in this article.

Composition and structure. Clearing for agriculture, lumber, and firewood has directly altered riparian vegetation along the Yampa River since European settlement in the 1870s. Although much of the clearing occurred before 1938, when the first aerial photographs were taken, total cover of mature cottonwood forest along the Yampa River near Hayden, Colorado, declined by 18% between 1938 and 1989. Even more striking, the average size of mature stands declined by 62% during that period (Noble 1993).

In addition to these broad-scale changes, the remaining forest stands have changed in composition and structure. Historic aerial photographs indicate that in heavily used areas, the crowns of individual trees were more widely spaced than in more inaccessible areas (such as islands). Thinning presumably increased light availability and the abundance of shade-intolerant grasses for livestock forage while decreasing native shade-tolerant understory species. Today, many previously thinned stands have responded by asexual root sprouting and filling in gaps with young cottonwood trees (Richter 1999), resulting in mixed-aged stands. A more typical age structure of cottonwood forests consists of even-aged cohorts of trees that result from stand establishment during episodic flood events. Forest thinning and subsequent asexual reproduction may have also resulted in decreased genetic diversity within stands (Richter 1999). Evaluating such changes in the composition and structure of the Yampa River's riparian mosaic has helped elucidate appropriate restoration strategies capable of reversing these trends.

Dominant environmental regimes. To increase understanding of the dynamic fluvial processes that shape and sustain the focal biodiversity along the Yampa River, TNC developed a conceptual ecological model of the riparian ecosystem (Figure 4; Richter 1999). Construction of the model helped to define the complex relationships between hydrologic and geomorphic processes and the internal patch types that make up the riparian mosaic, thus highlighting the key environmental regimes that must be conserved.

A quantitative computer simulation model was subsequently developed to determine the extent to which past or future human influences alter these relationships. The model was developed for a 19 km reach of the riparian corridor upstream from Hayden. Data sources for model construction and calibration included geographic infor-

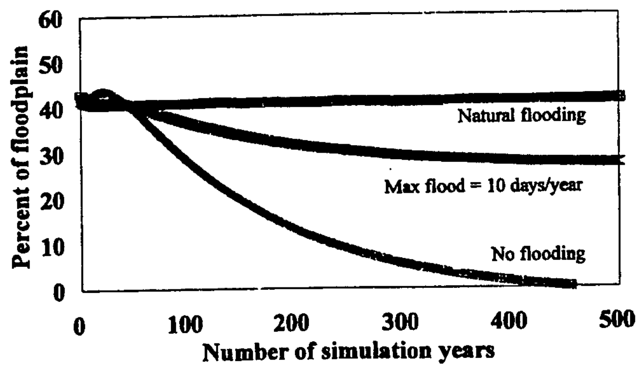


Figure 5. Simulation of Yampa River riparian dynamics. Variability in the abundance of mature cottonwood patches within the riparian ecosystem (from Figure 4) is predicted by a simulation model over a 500-year period associated with natural and altered flooding regimes (Richter and Richter in press). The graph illustrates the predicted abundance of mature cottonwood with natural flooding regime, with cumulative annual flooding duration limited to a maximum of 10 days each year (i.e., flood control), and with no flooding. Restricting flood duration to a maximum of 10 days each year shortened floods in 22% of the simulation years. Floods were defined as the flow equal to or greater than 125% of bankfull discharge.

mation system (GIS) maps of the riparian ecosystem derived from aerial photography, analysis of existing long-term streamflow records, calculation of geomorphic process rates (e.g., lateral channel migration), sampling of vegetation composition and structure, and tree dating (Richter 1999).

State variables used in the simulation model were the internal patch types that make up the Yampa River's riparian mosaic as defined by the conceptual model in Figure 4. The model simulated changes in the area and proportion of each patch type (i.e., percentage of the riparian area occupied) over time. Initial values for the area occupied by each patch type were derived from a 1938 vegetation map. Fluxes among state variables (represented by the arrows in Figure 4) were computed in the model by sets of difference equations that were updated during annual time steps. These equations represented the rates at which internal patch creation and destruction were expected, based on various levels of flooding and rates of plant succession. Patch-type abundance predicted at the end of the simulation period (1938–1989) was compared to actual patch-type abundance in 1989 as determined from aerial photos.

Discrepancies between model results and actual data initiated several new observations and insights. Channel sinuosity and lateral channel migration rates had changed relatively abruptly over the simulation period, suggesting channel instability. The Yampa River may have crossed a geomorphic threshold from a meandering to a braided channel. Narrowleaf cottonwood requires fresh alluvial deposits for seedling establishment, where subsequent floods will not destroy newly germinated seedlings. Although sufficient fresh depositional surfaces were still being produced in recent decades, these deposits no longer formed within protected meander bends but instead formed as mid-channel islands and lateral bars. Such changes in geomorphic processes have direct implications for cottonwood establishment, and they likely result in part from decreased bank stability due to deforestation of stream banks during the past century (Richter 1999).

After recalibration and validation of current and historic conditions, the model was used to explore the potential impacts of future hydrologic alterations due to a growing human population in the Yampa River watershed (Richter and Richter in press). Statistical evaluation of many flood variables (e.g., magnitude of flood peak, duration of bankfull flow) during model development suggested that the duration of floods may be the most important variable driving riparian dynamics. If the annual number of days in which streamflow exceeded 125% of the bankfull discharge were limited to 14 days or less, then the mean abundance of some patch types, such as mature cottonwood, would deviate outside the 90% confidence limits of natural flow regime simulations (Figure 5; Richter and Richter in press). Thus, the natural variability in flood duration will need to be conserved in the future to maintain the current level of functionality at this site.

Minimum dynamic area. The minimum dynamic area for the Yampa River riparian ecosystem must maintain recolonization sources for each internal patch type and provide room for the geomorphic processes that reshape the floodplain and create and destroy the complete array of patch types. Human alteration of riparian vegetation, along with an associated reduction in the width of the riparian corridor, may have important ramifications for minimum dynamic area. Remaining stands of riparian vegetation are primarily located adjacent to the active stream channel. Preferential clearing of vegetation has eliminated stands on the outer edges of the floodplain that would be most secure from catastrophic floods. Not only is riparian vegetation more vulnerable to widespread destruction by floods, but future sources of propagules for post-disturbance recovery may also be severely reduced as a result of a narrowed and fragmented riparian corridor.

Extensive human alteration of riparian vegetation has made it difficult to determine the natural extent (particularly the width) of the riparian corridor before European settlement. However, geologic maps depict the extent of alluvial deposits, which can be used to approximate the river's active "meander belt" since the Pleistocene. These alluvial deposits are equivalent to the maximum potential extent of the riparian ecosystem over the long term. Even the largest contemporary flood is unlikely to eliminate vegetation across the entire width of the meander belt,

allowing some refugia and sources of propagules for recolonization.

However, the exact extent of the minimum dynamic area for this riparian ecosystem remains undefined, and it likely differs from the maximum potential floodplain. Further analysis is warranted to more precisely define minimum dynamic area. In the interim, restoration of previously cleared areas located at the outer fringes of the floodplain and revegetation of denuded stream banks should be considered a high priority because they would help restore geomorphic processes. Until a catastrophic flood occurs, the long-term implications of an altered floodplain may not be realized.

Connectivity. A great deal of ecosystem and species diversity along the Yampa River is attributable to the steep elevation gradients in the watershed. The ability of the riparian ecosystem and associated species within the watershed to shift their elevation range as global climate change occurs may be critical to their long-term persistence. Therefore, representation of the entire elevation gradient along the Yampa River, from high-elevation headwater tributaries to lower-elevation reaches within the Wyoming Basin region, will likely be important for conservation of focal biodiversity.

Longitudinal connectivity between protected riparian areas within the watershed will also be important to maintain flows of energy, matter, and species. For example, propagules of riparian species commonly originate upstream or upwind of the open sand bars where they germinate. Lateral connectivity—particularly the interface of the riparian mosaic with uplands—is also important, especially if the conservation focus expands to include coarse- or regional-scale biodiversity. Currently, the longitudinal connectivity of this system has not been significantly altered within the watershed, but clearing of riparian forest has compromised lateral connectivity.

Conclusions

The Yampa River case study illustrates the importance and challenge of clearly defining the focus and scale of biodiversity conservation at a given site. Evaluating the four functional attributes relative to the target riparian ecosystem also provided important insights into management and restoration strategies needed to conserve the site.

Applying the core concepts articulated in this article to other conservation sites is essential because effective biodiversity conservation depends on functionality. Existing conservation areas, as well as remaining undeveloped or moderately altered areas, should be evaluated for their optimum potential to conserve biodiversity at multiple scales. In particular, it is critically important to identify and prioritize all remaining functional landscapes for future conservation. Such areas will likely remain viable over long time frames and provide the diverse environmental gradients and regimes necessary for biodiversity to respond to global change.

Yet, even with the integrated, multiscale framework presented in this article, great challenges exist for conservation practitioners. The natural ranges of variability for most patterns and processes will remain imperfectly known, with the possible exception of dominant processes that have been monitored for long periods (e.g., flooding regimes). Moreover, practitioners must somehow decide, based on extremely limited knowledge, the extent and level to which human impacts can be tolerated. A high priority for research is therefore to identify levels or thresholds of human alteration to natural ranges of variability that lead to unacceptable impoverishment of biodiversity.

The ability to incorporate the criteria we have outlined in applied conservation decisions is rapidly increasing as new tools and techniques (e.g., GIS, remote sensing imagery, simulation modeling, and long-term data sets) become available. New ecological research, increasing availability of powerful new technologies for assessing ecological systems, and growing conservation focus on the dynamic nature of ecological systems will all help practitioners incorporate ecosystem- and landscape-level concepts into biodiversity conservation to the greatest extent possible.

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Herbicide Effects on Groundcover Vegetation in Southern Pinelands:

A Literature Review

By

Andrea R. Litt

Brenda J. Herring

Louis Provencher

Longleaf Pine Restoration Project

The Nature Conservancy, University of Florida, and Tall Timbers Research Station

Report to the Gulf Coastal Plain Ecosystem Partnership

March 2000

Send correspondence to: Dr. Louis Provencher
Longleaf Pine Restoration Project
P.O. Box 875
Niceville, FL 32588-0875
Phone/FAX: 850-689-3669
Email: tnc@nuc.net

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Introduction

Longleaf pine forests once dominated the landscape of the southeastern United States. In their natural state, these open-structured forests have a high diversity of groundcover species and are maintained by fire. These habitats represent some of the most species-rich in the world, outside of the tropics (Peet and Allard 1993). Today, only 2% remains, much of which is fragmented and fire-suppressed (Myers 1990).

Reduction of hardwood encroachment into the midstory, which has occurred in the absence of fire, is very important for the purposes of maintaining diversity and threatened and endangered species, as well as for pine production. Opening the midstory can be accomplished with prescribed fire; however, due to management obstacles (e.g., smoke management, need for rapid hardwood reduction, concern about damage to pines), alternative methods have been explored (e.g., mechanical felling/girdling, herbicide application). Care must be taken when using these methods, due to the likelihood of soil disturbance occurring when using mechanical techniques and mortality of non-target species with herbicide application.

Herbicides were applied to 552,000 acres of forest lands in the southeast in 1992 to control woody and herbaceous species (Fallis 1993). While herbicide application is a generally accepted and widely used practice for site preparation in regeneration of pine plantations, and increasingly for mid-rotation release from competition, little is known about the effects on non-target species. The available information comes mainly from studies conducted in pine plantations, with very few experiments performed in natural forested habitat. Our goal was to compile the published data and document the effect of different herbicides on groundcover vegetation.

Methods

We conducted an intensive literature search regarding the effects of herbicides on groundcover vegetation in southern pinelands. Publications were obtained through computerized and traditional literature searches and by communicating with experts (Appendix 1). To be included, studies had to have a valid experimental design (i.e., a no-treatment control and replicates), be conducted in sandhills, flatwoods, or pine plantations in the southeast, and include quantitative data for species groups or particular species of interest (e.g., threatened and endangered species). Threatened and endangered species were identified using federal, state, and Nature Conservancy Natural Heritage ranks (Mississippi Natural Heritage Program 1997, Marois 1998). Wiregrass (*Aristida beyrichiana*, formerly *Aristida stricta*, Peet 1993) was added to this group for examination. Wiregrass is potentially sensitive to soil disturbance (Clewell 1989) and a significant species in fire management and the conservation of longleaf pine systems. We also eliminated food plot studies for wildlife or pure weed control studies.

More than 125 studies were examined, from which 21 useable studies were identified. Data were extracted from text, figures, and/or tables and some grouping was performed (Appendix 2). Species/life form groups were condensed to create 5 categories: 1) total; 2) herbaceous (includes forbs, legumes, non-legumes, ferns, and other herbaceous plants); 3) woody (includes arborescent, non-arborescent, woody, and semi-woody plants); 4) graminoids (includes grasses, sedges, and grass-like plants); and 5) woody vines. Response variables were grouped into species richness, Shannon diversity, Simpson diversity, importance value, cover, density, frequency, or biomass. Some response variables were not included due to infrequent use in the studies examined (e.g., Hill's index). No data were

included regarding pines or oaks (e.g., height, mortality), as we were only interested in the impacts on the groundcover plant community. We only included data corresponding to no-treatment control and herbicide treatment plots (i.e., no combination treatments such as herbicide + fertilization). If multiple years of data were provided, we only included data from immediately post-treatment and the last year of the study, and these values were averaged, to reduce complexity.

Some studies reported means adjusted for the pre-treatment condition, but most did not. The pre-treatment effect for control and treated areas was accounted for by calculating:

$$(X_{\text{post-treatment}} - X_{\text{pre-treatment}}) / X_{\text{pre-treatment}}.$$

We then calculated the % change in value compared to the control (impact of the herbicide),

$$100 * [(X_{\text{treatment}} - X_{\text{control}}) / X_{\text{control}}]$$

to obtain a relative measure. All data were grouped by two natural habitats (flatwoods and sandhills) and one artificial habitat (pine plantations), herbicide, response variable, and category. For studies using the same herbicide, we compiled data by calculating the weighted average of the % change in value (weighted by the number of replicates, n_i),

$$[(X_1 * n_1) + (X_2 * n_2) + ... + (X_i * n_i)] / (n_1 + n_2 + ... + n_i).$$

Results

Overview

The most telling result of this literature survey is the small number of studies that document herbicide effects on groundcover plants (Table 1). The paucity of data is especially evident in natural flatwoods and sandhills where we found, respectively, 3 and 7 studies. Moreover, at least six different herbicides were used among these studies. A greater number of cases (31) were found in pine plantations where weed control was the predominant reason for herbicide application (Table 1). Despite the greater number of studies involved, a greater number of herbicides and unique herbicide combinations were also employed, sometimes repeatedly. These differences hindered generalizations.

Flatwoods

All herbicides used in flatwoods reduced species richness and cover of herbaceous and woody plants (Table 2). The weakest effect was a 5.13% decrease in herbaceous species richness compared to the control due to Pronone® (Wilkins et al. 1993a). The strongest effect was a decline of 71.8% in total species richness using a mixture of sulfometuron, glyphosate, and triclopyr (Neary et al. 1991). In the one study that documented effects on cover, both herbaceous (27.2%) and woody vegetation (58.6%) declined after Pronone® application (Wilkins et al. 1993a).

Sandhills

Herbicide effects were more heterogeneous in sandhills. As expected, understory woody cover and density decreased following hexazinone application (10.3 to 55.9% depending on herbicides) (Boyer 1990, Wilkins et al. 1993a, Wilkins et al. 1993b, Brockway et al. 1998, Provencher et al. 2000b, Provencher et al., *unpublished data*), whereas woody biomass increased by 105.3% with 2,4 D (Kush et al. 1999) (Table 2). Graminoid density and cover increased with ULW® and Velpar-L® application (Wilkins et al. 1993b, Brockway et al. 1998, Provencher et al. 2000b, Provencher et al., *unpublished data*). Herbaceous cover experienced mixed effects: 49.8% increase with ULW® (Brockway et al. 1998, Provencher et al.,

unpublished data) as compared with 33% and 21.5% decreases with Pronone® and Velpar-L®, respectively (Wilkins et al. 1993a, Wilkins et al. 1993b, Brockway et al. 1998).

The effect on species richness depended on the herbicide (type and application rate), and therefore the different studies. Pronone® and ULW® decreased species richness by 55.2% (herbaceous) (Wilkins et al. 1993a) and 81% (total) (Brockway et al. 1998, Provencher at al. 2000b), respectively, whereas 2,4 D and Velpar-L® resulted in moderate increases by 6.4% and 12% (total) (Brockway et al. 1998, Kush et al. 1999).

Pine plantations

Due to the large number of herbicides, unique combinations used, and the heterogeneity of response variables, it was difficult to find commonality in the results (Table 2). Most herbicides increased herbaceous species richness with values ranging from 10.5% (dicamba + 2,4 D) to 84.7% (picloram) (Miller et al. 1999). Not surprisingly, woody species richness was negatively affected by all herbicides but declines never exceeded 17.2% (imazapyr) (Boyd et al. 1995). Graminoid species richness decreased by 16.7% with Velpar-L® (Boyd et al. 1995, Miller et al. 1999) but increased by 30.8% with triclopyr (Miller et al. 1999), with other herbicides yielding intermediate values (Table 2). Herbicides generally decreased total species richness, with the largest reduction produced by Pronone® (11.2%) (Blake 1986, Hurst and Blake 1987, Boyd et al. 1995, Miller et al. 1999). Triclopyr (Miller et al. 1999) and glyphosate (Boyd et al. 1995, Miller et al. 1999) increased total richness by 10.9% and 8.7%, respectively.

Importance value was reported for many different herbicides (Boyd et al. 1995, Miller et al 1999) (calculated slightly differently using the same component variables) (Table 2). The importance value of graminoids was unchanged by picloram, but increased with other herbicides by as much as 56.1% (triclopyr) (Miller et al. 1999). Herbaceous importance value only decreased by 27.4% with the combination of dicamba and 2,4 D, whereas it increased by as much as 133.3% under picloram application (Miller et al. 1999). This latter value was at least twice the increase reported for other herbicides (e.g., Velpar-L®) and their combinations. The effect of different herbicides on the importance value of woody species was very heterogeneous: a maximum 52.5% increase was found with imazapyr (Boyd et al. 1995), whereas the greatest decrease was detected for triclopyr (19.8%) (Miller et al. 1999). A little more than half the herbicides demonstrated reductions in this parameter.

Percent cover was the other most commonly reported response variable, but it was most closely associated with studies using unique combinations of herbicides. As expected, woody cover generally declined after application. The largest decrease of 92.8% was found for a combination of triclopyr, glyphosate, and sulfometuron applied repeatedly for 11 years (Zutter and Miller 1998). A combination of triclopyr and glyphosate applied annually for 5 years generated the only increase (150%) in woody cover (Miller et al. 1995). Herbaceous cover varied greatly between studies even when using combinations of the same herbicides, which may be due to differences in application sequences and rates. A combination of sulfometuron applied twice and glyphosate applied three times decreased herbaceous cover by 97.5%, the greatest decline noted (Zutter et al. 1986). A sequence of triclopyr applied twice followed by a mixture of triclopyr and glyphosate produced a maximum 70.9% increase in herbaceous cover (Lauer and Glover 1998). However, triclopyr alone resulted in a 43.8% increase when applied once (Lauer and Glover 1998) or 60% decrease when applied twice (Zutter and Miller 1998). Only two studies reported cover values for graminoids: a combination treatment of Velpar-L®, triclopyr, imazapyr, and glyphosate reduced graminoids

by 113.2% (Harrington and Edwards 1999) whereas triclopyr and glyphosate, applied annually for 5 years, barely increased it by 2% (Miller et al. 1995).

A few studies reported density, frequency, or biomass as response variables (Table 2). Herbaceous biomass closely mimicked cover in three cases (Zutter et al. 1986, Zutter et al. 1987). Little can be said about density and frequency due to the paucity of studies.

Species of Special Concern

Results for species of concern come from six studies conducted over several years (Table 3). We included wiregrass in this category as it is an important fuel in many natural pinelands. Pronone® decreased wiregrass (all *A. stricta* data refer to *A. beyrichiana*) by as much as 142% at intermediate or higher rates of application (Wilkins et al. 1993a). Other studies, however, reported increases of 7480% with Velpar-L® (Wilkins et al. 1993b), although the same herbicide applied elsewhere at approximately the same rates yielded more moderate increases of 22.3% (Brockway et al. 1998). Triclopyr initially increased *A. beyrichiana* frequency by 204.8% in south Mississippi flatwoods, but then the same population was decreased by 329.8% 5 months later compared to control plots (Clewell and Lasley 1998, Trial 1). Three years after ULW® application, hairy wild indigo (*Baptisia calycosa* var. *villosa*) and pineland hoary pea (*Tephrosia mohrii*) densities were all reduced by 100% and 59.7%, respectively (the first and third year post-treatment are consistent) (Provencher et al 2000b). The 100% decrease reported for *B. calycosa* var. *villosa* may be an artifact of small numbers. Again in south Mississippi flatwoods, beardgrass (*Andropogon capillipes*) decreased by 162.5% with triclopyr, but frequencies were generally too low to calculate a percent change compared to the control (Clewell and Lasley 1998). Low numbers also prevented us from measuring herbicide effects on myrtle holly (*Ilex myrtifolia*), huckleberry (*Gaylussacia frondosa*), and coastal plain beak sedge (*Rhyncospora stenophylla*) (Clewell and Lasley 1998).

Discussion

Our most notable finding was that the effects of herbicides on understory vegetation in natural flatwoods and sandhills have rarely been measured. In addition, we found a dearth of data on plant species because authors preferred grouping them as weeds, grasses, herbs, and so on. Therefore, it was generally not possible to distinguish between the responses of desirable and undesirable species. This is troublesome because the effects on species of management concern cannot generally be evaluated. For instance, when numbers were sufficient to calculate percent change, three threatened species in Mississippi, namely *B. calycosa* var. *villosa*, *T. mohrii*, and *A. capillipes*, all showed negative responses to the herbicides tested. Wiregrass was either stimulated or decreased, sometimes by the same herbicide, in different studies.

It is not clear that results from pine plantations, which included a greater number of studies, apply to natural forests because of the preponderance of early successional species associated with the disturbed soils (Grelen 1962, Campbell 1983, Conde et al 1983, Provencher et al. 2000a). As reported in many plantation studies, weed control was the reason to apply herbicides, suggesting the presence of aggressive ruderal species. This fact would also explain the elaborate combinations and repeated applications of herbicides more commonly reported in pine plantations than in natural forests. Therefore, studies may be reporting more conservative values for herbaceous and graminoid control because herbaceous weeds may show a greater resistance to herbicides than herbaceous non-weedy species.

Although herbicides on flatwood vegetation uniformly reduced species richness and herbaceous and woody cover, the same cannot be said about sandhills. The general pattern for sandhills was a decrease in woody species associated with an increase in graminoids after herbicide application. The responses of species richness and herbaceous cover or density were mixed and rarely exceeded 100%. Because so few studies were involved, it was not possible to determine if the herbicides or the study were the source of variation.

A troubling aspect of the herbicide literature we examined was the lack of experimental rigor and inconsistent reporting standards. A large number of studies lacked experimental designs, lacked clear descriptions of their designs and/or methods, were poorly, if at all replicated, lacked a control, performed no pre-treatment sampling, performed incorrect or no statistical analyses, reported no measure of variability (thus we could not perform meta-analysis [Gurevitch and Hedges 1999]), or only presented response variables as percent control without giving any of the numbers that led to this derivation. The studies we used were among the better ones, but many retained the least serious of these problems and only two studies reported standard errors or deviations. Finally, the fragmented nature of response variables and herbicide choices was our greatest challenge to reach general conclusions.

The above findings suggest that the widespread use of herbicides to control hardwoods in public and private southern pinelands (Fallis 1993) may be premature if concerned about non-target effects. Additional studies are needed before large landscapes should be treated. Furthermore, should agencies and private land owners decide to pay for the greater cost of herbicide application relative to prescribed burning (Provencher et al 2000b), implementation of rigorous experimental designs free of the problems listed above and a deliberate effort to track species of management concern should be the norm. This is especially true of public lands, which are extensive and more likely subject to large aerial application, that have a greater probability to impact diversity and species of concern.

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Table 1. Studies used in the literature review, categorized by habitat and herbicide.

Herbicide	*# of cases*	*Studies*
Flatwoods	**4**	
Hexazinone (Pronone)	1	Wilkins et al. 1993a[a]
Sulfometuron	1	Neary et al. 1984
Sulfometuron methyl + triclopyr	1	Neary et al. 1991
Sulfometuron methyl + sulfometuron methyl + glyphosate + glyphosate + [glyphosate + triclopyr] (repeated)	1	Neary et al. 1991
Sandhills	**10**	
2,4 D	2	Boyer 1990, Kush et al. 1999
Hexazinone (Pronone)	2	Berish 1996, Wilkins et al. 1993a[a]
Hexazinone (ULW)	3	Berish 1996, Brockway et al. 1998, Provencher et al. 2000b & *unpublished data*
Hexazinone (Velpar L)	3	Berish 1996, Brockway et al. 1998[a], Wilkins et al 1993b[a]
Pine plantations	**31**	
Dicamba + 2,4 D	1	Miller et al. 1999
Glyphosate	2	Boyd et al. 1995, Miller et al. 1999
Hexazinone (Pronone)	4	Boyd et al. 1995, Blake 1996, Hurst & Blake 1987, Miller et al. 1999

[a] This study was only counted once, but tests the effect of this particular herbicide at several different rates.

Herbicide	*# of cases*	*Studies*
Hexazinone (Velpar L)	4	Boyd et al. 1995, Blake 1996, Hurst & Blake 1987, Miller et al. 1999
Imazapyr	1	Boyd et al. 1995
Picloram	1	Miller et al. 1999
Triclopyr	4	Clewell & Lasley 1998 (Trials 1 & 3), Lauer & Glover 1998, Miller et al. 1999
Glyphosate + sulfometuron + sulfometuron + glyphosate (repeated as needed)	1	Zutter et al. 1987
Hexazinone (ULW) + sulfometuron + glyphosate + glyphosate + sulfometuron	1	Haywood et al. 1997
Hexazinone (Velpar L) + triclopyr ester + imazapyr + glyphosate	1	Harrington & Edwards 1999
Sulfometuron + glyphosate	1	Lauer & Glover 1998
Sulfometuron + sulfometuron + glyphosate + glyphosate + glyphosate	1	Zutter et al. 1986
Sulfometuron (repeated annually for 11 years) + glyphosate (repeated annually for 3 years)	1	Zutter & Miller 1998
Triclopyr + triclopyr + sulfometuron (repeated annually for 11 years) + glyphosate (repeated annually for 3 years)	1	Zutter & Miller 1998
Triclopyr + sulfometuron + glyphosate	1	Lauer & Glover 1998
Triclopyr + triclopyr	1	Zutter & Miller 1998
Triclopyr + triclopyr + [triclopyr + glyphosate]	1	Lauer & Glover 1998
Triclopyr + glyphosate (for 5 years)	1	Miller et al. 1995
Triclopyr ester + sulfometuron	2	Zutter et al. 1987, Zutter et al. 1986
Triclopyr + triclopyr + [triclopyr + glyphosate] + sulfometuron + glyphosate	1	Lauer & Glover 1998

Table 2. The number of studies, total number of replicates (N), average percent change (averaged by habitat and herbicide), and the respective study for each response variable, categorized by habitat and herbicide.

Herbicide	*Response variable*	*# of studies*	*Total N*	*Average % change*	*Studies*
FLATWOODS					
Hexazinone (Pronone)	**Species richness**				
	Herbaceous	1	9	-5.13	Wilkins et al. 1993a
	Woody	1	9	-35.64	Wilkins et al. 1993a
	Cover				
	Herbaceous	1	9	-27.24	Wilkins et al. 1993a
	Woody	1	9	-58.60	Wilkins et al. 1993a
Sulfometuron methyl + sulfometuron methyl + glyphosate + glyphosate + [glyphosate + triclopyr] (repeated)	**Species richness**				
	Total	1	108	-71.78	Neary et al. 1991
Sulfometuron methyl + triclopyr	**Species richness**				
	Total	1	150	-30.19	Neary et al. 1991
SANDHILLS					
2,4 D	**Species richness**				
	Total	1	3	6.36	Kush et al. 1999
	Herbaceous	1	3	3.33	Kush et al. 1999
	Woody	1	3	6.49	Kush et al. 1999
	Graminoids	1	3	6.67	Kush et al. 1999
	Woody vines	1	3	30.00	Kush et al. 1999
	Density				
	Woody	1	3	67.05	Boyer 1990
	Biomass				
	Total	1	3	82.70	Kush et al. 1999

Herbicide	*Response variable*	*# of studies*	*Total N*	*Average % change*	*Studies*
	Herbaceous	1	3	14.22	Kush et al. 1999
	Woody	1	3	105.36	Kush et al. 1999
	Woody vines	1	3	12.32	Kush et al. 1999
Hexazinone (Pronone)	**Species richness**				
	Herbaceous	1	9	-55.16	Wilkins et al. 1993a
	Woody	1	9	-42.90	Wilkins et al. 1993a
	Cover				
	Total	1	4	111.72	Berish 1996
	Herbaceous	1	9	-32.99	Wilkins et al. 1993a
	Woody	1	9	-55.89	Wilkins et al. 1993a
Hexazinone (ULW)	**Species richness**				
	Total	2	11	-80.90	Brockway et al. 1998, Provencher et al. 2000b
	Shannon diversity				
	Total	1	5	125.36	Brockway et al. 1998
	Cover				
	Total	1	4	333.87	Berish 1996
	Herbaceous	2	11	49.79	Brockway et al. 1998, Provencher et al., *unpublished data*
	Woody	2	11	-36.20	Brockway et al. 1998, Provencher et al., *unpublished data*
	Graminoids	2	11	96.30	Brockway et al. 1998, Provencher et al., *unpublished data*
	Density				
	Herbaceous	1	6	15.47	Provencher et al. 2000b
	Woody	1	6	-23.07	Provencher et al. 2000b
	Graminoids	1	6	26.09	Provencher et al. 2000b
	Woody vines	1	6	-13.98	Provencher et al. 2000b

Herbicide	*Response variable*	*# of studies*	*Total N*	*Average % change*	*Studies*
Hexazinone (Velpar L)	**Species richness**				
	Total	1	10	11.93	Brockway et al. 1998
	Shannon diversity				
	Total	1	5	18.57	Brockway et al. 1998
	Cover				
	Total	1	4	136.44	Berish 1996
	Herbaceous	2	19	-21.50	Brockway et al. 1998, Wilkins et al. 1993b
	Woody	2	19	-10.31	Brockway et al. 1998, Wilkins et al. 1993b
	Graminoids	2	19	698.28	Brockway et al. 1998, Wilkins et al. 1993b
PINE PLANTATIONS					
Dicamba + 2,4 D	**Species richness**				
	Total	1	4	-3.64	Miller et al. 1999
	Herbaceous	1	4	10.46	Miller et al. 1999
	Woody	1	4	-4.41	Miller et al. 1999
	Graminoids	1	4	-3.08	Miller et al. 1999
	Woody vines	1	4	-12.50	Miller et al. 1999
	Simpson diversity				
	Total	1	4	-2.20	Miller et al. 1999
	Shannon diversity				
	Total	1	4	-7.14	Miller et al. 1999
	Importance value				
	Herbaceous	1	4	-27.38	Miller et al. 1999
	Woody	1	4	8.41	Miller et al. 1999
	Graminoids	1	4	14.29	Miller et al. 1999
	Woody vines	1	4	-7.27	Miller et al. 1999
	Density				
	Woody	1	4	-50.00	Miller et al. 1999

Herbicide	*Response variable*	*# of studies*	*Total N*	*Average % change*	*Studies*
Glyphosate (Roundup)	**Species richness**				
	Total	2	7	8.73	Boyd et al. 1995, Miller et al. 1999
	Herbaceous	2	7	43.78	Boyd et al. 1995, Miller et al. 1999
	Woody	2	7	-6.63	Boyd et al. 1995, Miller et al. 1999
	Graminoids	2	7	12.86	Boyd et al. 1995, Miller et al. 1999
	Woody vines	2	7	8.57	Boyd et al. 1995, Miller et al. 1999
	Simpson diversity				
	Total	2	7	-0.30	Boyd et al. 1995, Miller et al. 1999
	Shannon diversity				
	Total	2	7	3.21	Boyd et al. 1995, Miller et al. 1999
	Importance value				
	Herbaceous	2	7	16.03	Boyd et al. 1995, Miller et al. 1999
	Woody	2	7	-2.32	Boyd et al. 1995, Miller et al. 1999
	Graminoids	2	7	33.31	Boyd et al. 1995, Miller et al. 1999
	Woody vines	2	7	-0.59	Boyd et al. 1995, Miller et al. 1999
	Density				
	Woody	2	7	-62.34	Boyd et al. 1995, Miller et al. 1999
Glyphosate + sulfometuron + sulfometuron + glyphosate (repeated as needed)	**Simpson diversity**				
	Total	1	4	74.91	Zutter et al. 1987
	Shannon diversity				
	Total	1	4	-28.70	Zutter et al. 1987
	Cover				
	Herbaceous	1	4	-84.28	Zutter et al. 1987
	Biomass				
	Herbaceous	1	4	-95.32	Zutter et al. 1987

Herbicide	*Response variable*	*# of studies*	*Total N*	*Average % change*	*Studies*
Hexazinone (Pronone)	**Species richness**				
	Total	4	17	-11.20	Boyd et al. 1995, Blake 1986, Hurst & Blake 1987, Miller et al. 1999
	Herbaceous	2	7	38.36	Boyd et al. 1995, Miller et al. 1999
	Woody	2	7	-3.34	Boyd et al. 1995, Miller et al. 1999
	Graminoids	2	7	5.97	Boyd et al. 1995, Miller et al. 1999
	Woody vines	2	7	-6.43	Boyd et al. 1995, Miller et al. 1999
	Simpson diversity				
	Total	2	7	-1.72	Boyd et al. 1995, Miller et al. 1999
	Shannon diversity				
	Total	2	7	1.17	Boyd et al. 1995, Miller et al. 1999
	Importance value				
	Herbaceous	2	7	19.37	Boyd et al. 1995, Miller et al. 1999
	Woody	2	7	-8.81	Boyd et al. 1995, Miller et al. 1999
	Graminoids	2	7	8.47	Boyd et al. 1995, Miller et al. 1999
	Woody vines	2	7	9.90	Boyd et al. 1995, Miller et al. 1999
	Density				
	Woody	2	7	0.78	Boyd et al. 1995, Miller et al. 1999
	Biomass				
	Total	1	5	-26.35	Blake 1986
Hexazinone (ULW) + sulfometuron + glyphosate + glyphosate + sulfometuron	**Density**				
	Woody	1	3	-82.65	Haywood et al. 1997
	Woody vines	1	3	35.76	Haywood et al. 1997

Herbicide	*Response variable*	*# of studies*	*Total N*	*Average % change*	*Studies*
	Biomass				
	Herbaceous	1	3	-95.32	Haywood et al. 1997
Hexazinone (Velpar L)	**Species richness**				
	Total	4	17	-7.27	Boyd et al. 1995, Blake 1986, Hurst & Blake 1987, Miller et al. 1999
	Herbaceous	2	7	24.31	Boyd et al. 1995, Miller et al. 1999
	Woody	2	7	-12.16	Boyd et al. 1995, Miller et al. 1999
	Graminoids	2	7	-16.74	Boyd et al. 1995, Miller et al. 1999
	Woody vines	2	7	0.71	Boyd et al. 1995, Miller et al. 1999
	Simpson diversity				
	Total	2	7	-5.61	Boyd et al. 1995, Miller et al. 1999
	Shannon diversity				
	Total	2	7	-8.37	Boyd et al. 1995, Miller et al. 1999
	Importance value				
	Herbaceous	2	7	57.71	Boyd et al. 1995, Miller et al. 1999
	Woody	2	7	-15.87	Boyd et al. 1995, Miller et al. 1999
	Graminoids	2	7	38.10	Boyd et al. 1995, Miller et al. 1999
	Woody vines	2	7	24.99	Boyd et al. 1995, Miller et al. 1999
	Density				
	Woody	2	7	47.01	Boyd et al. 1995, Miller et al. 1999
	Biomass				
	Total	1	5	-21.90	Blake 1986
Hexazinone (Velpar L) + triclopyr ester + imazapyr + glyphosate	**Species richness**				
	Herbaceous	1	6	20.00	Harrington & Edwards 1999

Herbicide	Response variable	# of studies	Total N	Average % change	Studies
	Cover				
	Herbaceous	1	6	1.88	Harrington & Edwards 1999
	Woody	1	6	-81.29	Harrington & Edwards 1999
	Graminoids	1	6	-113.20	Harrington & Edwards 1999
	Woody vines	1	6	129.02	Harrington & Edwards 1999
	Density				
	Total	1	6	110.56	Harrington & Edwards 1999
Imazapyr (Arsenal)	**Species richness**				
	Total	1	3	-2.67	Boyd et al. 1995
	Herbaceous	1	3	13.49	Boyd et al. 1995
	Woody	1	3	-17.25	Boyd et al. 1995
	Graminoids	1	3	-3.33	Boyd et al. 1995
	Woody vines	1	3	33.33	Boyd et al. 1995
	Simpson diversity				
	Total	1	3	-9.78	Boyd et al. 1995
	Shannon diversity				
	Total	1	3	-7.50	Boyd et al. 1995
	Importance value				
	Herbaceous	1	3	45.40	Boyd et al. 1995
	Woody	1	3	52.48	Boyd et al. 1995
	Graminoids	1	3	30.23	Boyd et al. 1995
	Woody vines	1	3	-3.62	Boyd et al. 1995
	Density				
	Woody	1	3	-60.61	Boyd et al. 1995
Picloram	**Species richness**				
	Total	1	4	-3.64	Miller et al. 1999
	Herbaceous	1	4	84.70	Miller et al. 1999
	Woody	1	4	-0.52	Miller et al. 1999
	Graminoids	1	4	-10.77	Miller et al. 1999
	Woody vines	1	4	-6.25	Miller et al. 1999

Herbicide	*Response variable*	*# of studies*	*Total N*	*Average % change*	*Studies*
	Simpson diversity				
	Total	1	4	-2.20	Miller et al. 1999
	Shannon diversity				
	Total	1	4	-7.14	Miller et al. 1999
	Importance value				
	Herbaceous	1	4	133.34	Miller et al. 1999
	Woody	1	4	9.68	Miller et al. 1999
	Graminoids	1	4	0.00	Miller et al. 1999
	Woody vines	1	4	-12.73	Miller et al. 1999
	Density				
	Woody	1	4	-65.00	Miller et al. 1999
Sulfometuron + glyphosate	**Cover**				
	Herbaceous	1	10	-11.47	Lauer & Glover 1998
	Woody	1	10	-7.74	Lauer & Glover 1998
Sulfometuron (annually for 11 years) + glyphosate (annually for 3 years)	**Cover**				
	Herbaceous	1	5	-86.67	Zutter & Miller 1998
	Woody	1	5	-27.71	Zutter & Miller 1998
Sulfometuron + sulfometuron + glyphosate + glyphosate + glyphosate	**Cover**				
	Herbaceous	1	4	-97.52	Zutter et al. 1986
	Woody	1	4	-66.67	Zutter et al. 1986
	Biomass				
	Herbaceous	1	4	-99.14	Zutter et al. 1986
	Woody	1	4	-47.26	Zutter et al. 1986
Triclopyr	**Species richness**				
	Total	1	4	10.91	Miller et al. 1999
	Herbaceous	1	4	68.79	Miller et al. 1999
	Woody	1	4	-2.27	Miller et al. 1999

Herbicide	*Response variable*	*# of studies*	*Total N*	*Average % change*	*Studies*
	Graminoids	1	4	30.77	Miller et al. 1999
	Woody vines	1	4	-8.75	Miller et al. 1999
	Simpson diversity				
	Total	1	4	-1.10	Miller et al. 1999
	Shannon diversity				
	Total	1	4	0.00	Miller et al. 1999
	Importance value				
	Herbaceous	1	4	67.07	Miller et al. 1999
	Woody	1	4	-19.77	Miller et al. 1999
	Graminoids	1	4	57.14	Miller et al. 1999
	Woody vines	1	4	-10.91	Miller et al. 1999
	Cover				
	Herbaceous	1	10	43.84	Lauer & Glover 1998
	Woody	1	10	-67.36	Lauer & Glover 1998
	Density				
	Woody	1	4	-55.00	Miller et al. 1999
	Frequency				
	Herbaceous	2	6	-76.25	Clewell & Lasley 1998 (Trial 1, 3)
	Woody	2	6	787.88	Clewell & Lasley 1998 (Trial 1, 3)
	Graminoids	2	6	517.95	Clewell & Lasley 1998 (Trial 1, 3)
Triclopyr + triclopyr	**Cover**				
	Herbaceous	1	5	-60.00	Zutter & Miller 1998
	Woody	1	5	-59.04	Zutter & Miller 1998
Triclopyr ester + sulfometuron	**Simpson diversity**				
	Total	1	4	25.24	Zutter et al. 1987
	Shannon diversity				
	Total	1	4	-8.44	Zutter et al. 1987
	Cover				
	Herbaceous	2	8	-32.44	Zutter et al. 1987, Zutter et al. 1986
	Woody	1	4	-16.67	Zutter et al. 1986

Herbicide	*Response variable*	*# of studies*	*Total N*	*Average % change*	*Studies*
	Biomass				
	Herbaceous	2	8	-32.13	Zutter et al. 1987, Zutter et al. 1986
	Woody	1	4	-12.69	Zutter et al. 1986
Triclopyr + triclopyr + sulfometuron (annually for 11 years) + glyphosate (annually for 3 years)	**Cover**				
	Herbaceous	1	5	-86.67	Zutter & Miller 1998
	Woody	1	5	-92.77	Zutter & Miller 1998
Triclopyr + sulfometuron + glyphosate	**Cover**				
	Herbaceous	1	10	15.71	Lauer & Glover 1998
	Woody	1	10	-70.58	Lauer & Glover 1998
Triclopyr + glyphosate (for 5 years)	**Cover**				
	Total	1	53	-5.00	Miller et al. 1995
	Herbaceous	1	53	7.67	Miller et al. 1995
	Woody	1	53	150.00	Miller et al. 1995
	Graminoids	1	53	2.09	Miller et al. 1995
	Woody vines	1	53	26.19	Miller et al. 1995
Triclopyr + triclopyr + [triclopyr + glyphosate]	**Cover**				
	Herbaceous	1	10	70.90	Lauer & Glover 1998
	Woody	1	10	-76.47	Lauer & Glover 1998
Triclopyr + triclopyr + [triclopyr + glyphosate] + sulfometuron + glyphosate	**Cover**				
	Herbaceous	1	10	31.37	Lauer & Glover 1998
	Woody	1	10	-69.86	Lauer & Glover 1998

Table 3. Herbicide, application rate, time since treatment, number of replicates (N), treatment value, control (untreated) value, and percent change for response variables for species of special concern or of interest (e.g., wiregrass), categorized by habitat and herbicide. All *Aristida stricta* refer to *A. beyrichiana* (Peet 1993).

Species	*Herbicide*	*Rate*	*Time post-treatment*	*Response variable*	*N*	*Treatment*	*Control*	*% change*	*Studies*
FLATWOODS									
Aristida stricta	Sulfometuron methyl	0.50 lb ai/ac 0.56 kg ai/ha	3 months	cover	108	0.90	2.50	-64.00	Neary et al. 1984
SANDHILLS									
Aristida stricta	Hexazinone (Pronone)	1.52 lb ai/ac 1.7 kg ai/ha	1 year	cover	3	1.00	1.76	-43.18	Wilkins et al 1993a
Aristida stricta	Hexazinone (Pronone)	1.52 lb ai/ac 1.7 kg ai/ha	2 years	cover	3	3.07	3.44	-10.76	Wilkins et al 1993a
Aristida stricta	Hexazinone (Pronone)	3.03 lb ai/ac 3.4 kg ai/ha	1 year	cover	3	-0.74	1.76	-142.05	Wilkins et al 1993a
Aristida stricta	Hexazinone (Pronone)	3.03 lb ai/ac 3.4 kg ai/ha	2 years	cover	3	1.09	3.44	-68.31	Wilkins et al 1993a
Aristida stricta	Hexazinone (Pronone)	6.07 lb ai/ac 6.8 kg ai/ha	1 year	cover	3	-0.74	1.76	-142.05	Wilkins et al 1993a
Aristida stricta	Hexazinone (Pronone)	6.07 lb ai/ac 6.8 kg ai/ha	2 years	cover	3	-0.89	3.44	-125.87	Wilkins et al 1993a
Aristida beyrichiana	Hexazinone (ULW)	1.50 lb ai/ac 1.68 kg ai/ha	1 year	density	6	0.12	0.10	20.00	Provencher et al. 2000b

Species	*Herbicide*	*Rate*	*Time post-treatment*	*Response variable*	*N*	*Treatment*	*Control*	*% change*	*Studies*
Aristida beyrichiana	Hexazinone (ULW)	1.50 lb ai/ac 1.68 kg ai/ha	3 years	density	6	0.11	0.10	10.00	Provencher et al. 2000b
Aristida stricta	Hexazinone (ULW)	0.98 lb ai/ac 1.10 kg ai/ha	nd[b]	cover	5	61.70	57.80	6.75	Brockway et al. 1998
Baptisia calycosa var. *villosa*	Hexazinone (ULW)	1.50 lb ai/ac 1.68 kg ai/ha	1 year	density	6	0.00	0.01	-100.00	Provencher et al. 2000b
Baptisia calycosa var. *villosa*	Hexazinone (ULW)	1.50 lb ai/ac 1.68 kg ai/ha	3 years	density	6	0.00	0.01	-100.00	Provencher et al. 2000b
Tephrosia mohrii	Hexazinone (ULW)	1.50 lb ai/ac 1.68 kg ai/ha	1 year	density	6	0.40	0.92	-56.52	Provencher et al. 2000b
Tephrosia mohrii	Hexazinone (ULW)	1.50 lb ai/ac 1.68 kg ai/ha	3 years	density	6	0.29	0.72	-59.72	Provencher et al. 2000b
Aristida stricta	Hexazinone (Velpar L)	0.37 lb ai/ac 0.42 kg ai/ha	1 year	cover	3	0.90	0.05	1700.00	Wilkins et al. 1993b
Aristida stricta	Hexazinone (Velpar L)	0.75 lb ai/ac 0.84 kg ai/ha	1 year	cover	3	0.65	0.05	1200.00	Wilkins et al. 1993b
Aristida stricta	Hexazinone (Velpar L)	1.50 lb ai/ac 1.68 kg ai/ha	1 year	cover	3	3.79	0.05	7480.00	Wilkins et al. 1993b
Aristida stricta	Hexazinone (Velpar L)	0.98 lb ai/ac 1.10 kg ai/ha	nd[b]	cover	5	61.20	57.80	5.88	Brockway et al. 1998

[b] The values presented are based on the adjusted mean taken from this paper. We could not determine if this value was based on an average of all three seasons of data or solely the last year (2.5 year post-treatment).

Species	*Herbicide*	*Rate*	*Time post-treatment*	*Response variable*	*N*	*Treatment*	*Control*	*% change*	*Studies*
Aristida stricta	Hexazinone (Velpar L)	1.96 lb ai/ac 2.2 kg ai/ha	nd[b]	cover	5	70.70	57.80	22.32	Brockway et al. 1998
PINE PLANTATIONS									
Andropogon capillipes	Triclopyr	0.40%	7 months	frequency	3	-1.00	-1.00	0.00	Clewell & Lasley 1998 (Trial 1)
Andropogon capillipes	Triclopyr	0.40%	12 months	frequency	3	1.00	0.00	-	Clewell & Lasley 1998 (Trial 1)
Andropogon capillipes	Triclopyr	0.40%	7 months	frequency	3	-1.00	-1.00	0.00	Clewell & Lasley 1998 (Trial 3)
Andropogon capillipes	Triclopyr	0.40%	12 months	frequency	3	0.50	-0.80	-162.50	Clewell & Lasley 1998 (Trial 3)
Aristida stricta	Triclopyr	0.40%	7 months	frequency	3	-0.27	-0.09	204.78	Clewell & Lasley 1998 (Trial 1)
Aristida stricta	Triclopyr	0.40%	12 months	frequency	3	-0.16	0.07	-329.79	Clewell & Lasley 1998 (Trial 1)
Aristida stricta	Triclopyr	0.40%	7 months	frequency	3	nd[c]	nd[d]	-	Clewell & Lasley 1998 (Trial 3)
Aristida stricta	Triclopyr	0.40%	12 months	frequency	3	nd[c]	nd[d]	-	Clewell & Lasley 1998 (Trial 3)
Ilex myrtifolia	Triclopyr	0.40%	7 months	frequency	3	nd[c]	0.00	-	Clewell & Lasley 1998 (Trial 1)
Ilex myrtifolia	Triclopyr	0.40%	12 months	frequency	3	nd[c]	-1.00	-	Clewell & Lasley 1998 (Trial 1)
Gaylussacia frondosa	Triclopyr	0.40%	7 months	frequency	3	nd[d]	0.00	-	Clewell & Lasley 1998 (Trial 3)

[c] Species was not present at pre-treatment.
[d] Species was not present at all during the study.

Species	*Herbicide*	*Rate*	*Time post-treatment*	*Response variable*	*N*	*Treatment*	*Control*	*% change*	*Studies*
Gaylussacia frondosa	Triclopyr	0.40%	12 months	frequency	3	nd[d]	0.00	-	Clewell & Lasley 1998 (Trial 3)
Rhynchospora stenophylla	Triclopyr	0.40%	7 months	frequency	3	nd[c]	nd[d]	-	Clewell & Lasley 1998 (Trial 1)
Rhynchospora stenophylla	Triclopyr	0.40%	12 months	frequency	3	nd[d]	nd[d]	-	Clewell & Lasley 1998 (Trial 1)

Appendix 1. List of herbicide-related articles and abstracts.

ARTICLES

Andariese, S. W., and P. M. Vitousek. 1988. Soil nitrogen turnover is altered by herbicide treatment in a North Carolina Piedmont. Forest Ecology and Management 23:19-25.

Beckwith, S. L. 1964. Effect of site preparation on wildlife and vegetation in the sandhills of central Florida. Proceedings of the Eighteenth Annual Conference of the Southeastern Association of Game and Fish Commission 18:39-48.

Berish, S. J. 1996. Efficacy of three formulations of the forest herbicide hexazinone as an aid to restoration of longleaf pine (*Pinus palustris*) sandhills at Eglin Air Force Base, Florida. M.S. thesis, University of Florida, Gainesville, FL.

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ABSTRACTS

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Appendix 2. Complete data for studies used, categorized by habitat. *Group* corresponds to the categorization of the variables, as designated by the authors. *Category* is the grouping we implemented for this study (i.e., total, herbaceous, woody, graminoids, or woody vines). N equals the total number of replicates considered. Percent change is equal to (treatment - control) / control.

Study	*Herbicide*	*Group*	*Category*	*Response variable*	N	*Treatment*	*Control*	*% change*
FLATWOODS								
Neary et al. 1991	Sulfometuron methyl (0.50 lbs ai/ac) (0.56 kg ai/ha) + sulfometuron methyl (0.25 lbs ai/ac) (0.28 kg ai/ha) + glyphosate (2%) + glyphosate (2%) + [glyphosate + triclopyr] (repeated) (2%)	Total	Total	Species richness	108	3.02	10.70	-71.78
	Sulfometuron methyl (0.37 lbs ai/ac) (0.42 kg ai/ha)+ triclopyr (5% ester, 6.6% amine in 4.17 gal water/ac or 39 L water/ha)	Total	Total	Species richness	150	5.41	7.75	-30.19
Wilkins et al. 1993a	Hexazinone (Pronone 10G) (1.52 lbs ai/ac) (1.7 kg ai/ha)	Herbaceous (yr 1)	Herbaceous	Species richness	3	9.50	9.00	5.56
	Hexazinone (Pronone 10G) (1.52 lbs ai/ac) (1.7 kg ai/ha)	Herbaceous (yr 2)	Herbaceous	Species richness	3	17.30	12.40	39.52
	Hexazinone (Pronone 10G) (1.52 lbs ai/ac) (1.7 kg ai/ha)	Woody (yr 1)	Woody	Species richness	3	7.20	10.30	-30.10
	Hexazinone (Pronone 10G) (1.52 lbs ai/ac) (1.7 kg ai/ha)	Woody (yr 2)	Woody	Species richness	3	10.10	11.20	-9.82
	Hexazinone (Pronone 10G) (3.03 lbs ai/ac) (3.4 kg ai/ha)	Herbaceous (yr 1)	Herbaceous	Species richness	3	5.60	9.00	-37.78
	Hexazinone (Pronone 10G) (3.03 lbs ai/ac) (3.4 kg ai/ha)	Herbaceous (yr 2)	Herbaceous	Species richness	3	16.10	12.40	29.84
	Hexazinone (Pronone 10G) (3.03 lbs ai/ac) (3.4 kg ai/ha)	Woody (yr 1)	Woody	Species richness	3	7.20	10.30	-30.10
	Hexazinone (Pronone 10G) (3.03 lbs ai/ac) (3.4 kg ai/ha)	Woody (yr 2)	Woody	Species richness	3	9.60	11.20	-14.29
	Hexazinone (Pronone 10G) (6.07 lbs ai/ac) (6.8 kg ai/ha)	Herbaceous (yr 1)	Herbaceous	Species richness	3	0.20	9.00	-97.78

Study	*Herbicide*	*Group*	*Category*	*Response variable*	*N*	*Treatment*	*Control*	*% change*
	Hexazinone (Pronone 10G) (6.07 lbs ai/ac) (6.8 kg ai/ha)	Herbaceous (yr 2)	Herbaceous	Species richness	3	16.10	12.40	29.84
	Hexazinone (Pronone 10G) (6.07 lbs ai/ac) (6.8 kg ai/ha)	Woody (yr 1)	Woody	Species richness	3	2.20	10.30	-78.64
	Hexazinone (Pronone 10G) (6.07 lbs ai/ac) (6.8 kg ai/ha)	Woody (yr 2)	Woody	Species richness	3	5.50	11.20	-50.89
	Hexazinone (Pronone 10G) (1.52 lbs ai/ac) (1.7 kg ai/ha)	Herbaceous (yr 1)	Herbaceous	Cover	3	20.70	61.00	-66.07
	Hexazinone (Pronone 10G) (1.52 lbs ai/ac) (1.7 kg ai/ha)	Herbaceous (yr 2)	Herbaceous	Cover	3	76.90	54.90	40.07
	Hexazinone (Pronone 10G) (1.52 lbs ai/ac) (1.7 kg ai/ha)	Woody (yr 1)	Woody	Cover	3	11.80	26.20	-54.96
	Hexazinone (Pronone 10G) (1.52 lbs ai/ac) (1.7 kg ai/ha)	Woody (yr 2)	Woody	Cover	3	22.40	42.80	-47.66
	Hexazinone (Pronone 10G) (3.03 lbs ai/ac) (3.4 kg ai/ha)	Herbaceous (yr 1)	Herbaceous	Cover	3	4.40	61.00	-92.79
	Hexazinone (Pronone 10G) (3.03 lbs ai/ac) (3.4 kg ai/ha)	Herbaceous (yr 2)	Herbaceous	Cover	3	68.20	54.90	24.23
	Hexazinone (Pronone 10G) (3.03 lbs ai/ac) (3.4 kg ai/ha)	Woody (yr 1)	Woody	Cover	3	8.30	26.20	-68.32
	Hexazinone (Pronone 10G) (3.03 lbs ai/ac) (3.4 kg ai/ha)	Woody (yr 2)	Woody	Cover	3	24.50	42.80	-42.76
	Hexazinone (Pronone 10G) (6.07 lbs ai/ac) (6.8 kg ai/ha)	Herbaceous (yr 1)	Herbaceous	Cover	3	0.00	61.00	-100.00
	Hexazinone (Pronone 10G) (6.07 lbs ai/ac) (6.8 kg ai/ha)	Herbaceous (yr 2)	Herbaceous	Cover	3	72.00	54.90	31.15
	Hexazinone (Pronone 10G) (6.07 lbs ai/ac) (6.8 kg ai/ha)	Woody (yr 1)	Woody	Cover	3	6.30	26.20	-75.95
	Hexazinone (Pronone 10G) (6.07 lbs ai/ac) (6.8 kg ai/ha)	Woody (yr 2)	Woody	Cover	3	16.30	42.80	-61.92

Study	*Herbicide*	*Group*	*Category*	*Response variable*	*N*	*Treatment*	*Control*	*% change*
SANDHILLS								
Berish 1996	Hexazinone (Pronone Powerpellet) (1.5 lbs ai/ac) (1.68 kg ai/ha)	Total groundcover	Total	Cover	4	-13.19	-6.23	111.72
	Hexazinone (ULW) (1.5 lbs ai/ac) (1.68 kg ai/ha)	Total groundcover	Total	Cover	4	-27.03	-6.23	333.87
	Hexazinone (Velpar L) (1.5 lbs ai/ac) (1.68 kg ai/ha)	Total groundcover	Total	Cover	4	-14.73	-6.23	136.44
Boyer 1990	2,4 D (1986) undiluted injection (0.017 oz/in. DBH) (1 ml/2.54 cm)	Woody	Woody	Cover	3	220.00	317.00	-30.60
	2,4 D (1989) undiluted injection (0.017 oz/in. DBH) (1 ml/2.54 cm)	Woody	Woody	Density (/ac)	3	343.00	270.00	27.04
	2,4 D (1989) undiluted injection (0.017 oz/in. DBH) (1 ml/2.54 cm)	Shrubs (1 inch dbh)	Woody	Density (/ac)	3	220.00	53.00	315.09
	2,4 D (1989) undiluted injection (0.017 oz/in. DBH) (1 ml/2.54 cm)	Trees (1 inch dbh)	Woody	Density (/ac)	3	123.00	217.00	-43.32
Brockway et al. 1998	Hexazinone (ULW) (0.98 lbs ai/ac) (1.1 kg ai/ha)	Total (Fall 1991)	Total	Species richness	5	-0.27	0.16	-268.75
	Hexazinone (ULW) (0.98 lbs ai/ac) (1.1 kg ai/ha)	Total (Fall 1993)	Total	Species richness	5	0.00	0.19	-100.00
	Hexazinone (Velpar L) (0.98 lbs ai/ac) (1.1 kg ai/ha)	Total (Fall 1991)	Total	Species richness	5	0.23	0.16	43.75
	Hexazinone (Velpar L) (0.98 lbs ai/ac) (1.1 kg ai/ha)	Total (Fall 1993)	Total	Species richness	5	0.28	0.19	47.37
	Hexazinone (Velpar L) (1.96 lbs ai/ac) (2.2 kg ai/ha)	Total (Fall 1991)	Total	Species richness	5	0.04	0.16	-75.00
	Hexazinone (Velpar L) (1.96 lbs ai/ac) (2.2 kg ai/ha)	Total (Fall 1993)	Total	Species richness	5	0.25	0.19	31.58
	Hexazinone (ULW) (0.98 lbs ai/ac) (1.1 kg ai/ha)	Total (Fall 1991)	Total	Shannon diversity	5	-0.34	-0.07	385.71
	Hexazinone (ULW) (0.98 lbs ai/ac) (1.1 kg ai/ha)	Total (Fall 1993)	Total	Shannon diversity	5	-0.07	0.20	-135.00
	Hexazinone (Velpar L) (0.98 lbs ai/ac) (1.1 kg ai/ha)	Total (Fall 1991)	Total	Shannon diversity	5	-0.15	-0.07	114.29

Study	*Herbicide*	*Group*	*Category*	*Response variable*	*N*	*Treatment*	*Control*	*% change*
	Hexazinone (Velpar L) (0.98 lbs ai/ac) (1.1 kg ai/ha)	Total (Fall 1993)	Total	Shannon diversity	5	-0.03	0.20	-115.00
	Hexazinone (Velpar L) (1.96 lbs ai/ac) (2.2 kg ai/ha)	Total (Fall 1991)	Total	Shannon diversity	5	-0.21	-0.07	200.00
	Hexazinone (Velpar L) (1.96 lbs ai/ac) (2.2 kg ai/ha)	Total (Fall 1993)	Total	Shannon diversity	5	-0.05	0.20	-125.00
	Hexazinone (ULW) (0.98 lbs ai/ac) (1.1 kg ai/ha)	Graminoids	Graminoids	Cover	5	70.10	65.60	6.86
	Hexazinone (ULW) (0.98 lbs ai/ac) (1.1 kg ai/ha)	Forbs	Herbaceous	Cover	5	7.70	8.60	-10.47
	Hexazinone (ULW) (0.98 lbs ai/ac) (1.1 kg ai/ha)	Shrubs	Woody	Cover	5	7.50	8.70	-13.79
	Hexazinone (ULW) (0.98 lbs ai/ac) (1.1 kg ai/ha)	Woody plants	Woody	Cover	5	0.27	1.46	-81.51
	Hexazinone (Velpar L) (0.98 lbs ai/ac) (1.1 kg ai/ha)	Graminoids	Graminoids	Cover	5	74.50	65.60	13.57
	Hexazinone (Velpar L) (0.98 lbs ai/ac) (1.1 kg ai/ha)	Forbs	Herbaceous	Cover	5	9.60	8.60	11.63
	Hexazinone (Velpar L) (0.98 lbs ai/ac) (1.1 kg ai/ha)	Shrubs	Woody	Cover	5	6.00	8.70	-31.03
	Hexazinone (Velpar L) (0.98 lbs ai/ac) (1.1 kg ai/ha)	Woody plants	Woody	Cover	5	-0.39	1.46	-126.71
	Hexazinone (Velpar L) (1.96 lbs ai/ac) (2.2 kg ai/ha)	Graminoids	Graminoids	Cover	5	72.70	65.60	10.82
	Hexazinone (Velpar L) (1.96 lbs ai/ac) (2.2 kg ai/ha)	Forbs	Herbaceous	Cover	5	10.30	8.60	19.77
	Hexazinone (Velpar L) (1.96 lbs ai/ac) (2.2 kg ai/ha)	Shrubs	Woody	Cover	5	3.40	8.70	-60.92
	Hexazinone (Velpar L) (1.96 lbs ai/ac) (2.2 kg ai/ha)	Woody plants	Woody	Cover	5	-0.39	1.46	-126.71
Kush et al. 1999	2,4 D undiluted injection (0.017 oz/in. DBH) (1 ml/2.54 cm)	Grasses	Graminoids	Species richness	3	16.00	15.00	6.67

Study	*Herbicide*	*Group*	*Category*	*Response variable*	*N*	*Treatment*	*Control*	*% change*
	2,4 D undiluted injection (0.017 oz/in. DBH) (1 ml/2.54 cm)	Forbs	Herbaceous	Species richness	3	62.00	60.00	3.33
	2,4 D undiluted injection (0.017 oz/in. DBH) (1 ml/2.54 cm)	Total	Total	Species richness	3	117.00	110.00	6.36
	2,4 D undiluted injection (0.017 oz/in. DBH) (1 ml/2.54 cm)	Shrubs	Woody	Species richness	3	14.00	11.00	27.27
	2,4 D undiluted injection (0.017 oz/in. DBH) (1 ml/2.54 cm)	Trees (understory)	Woody	Species richness	3	12.00	14.00	-14.29
	2,4 D undiluted injection (0.017 oz/in. DBH) (1 ml/2.54 cm)	Woody vines	Woody vines	Species richness	3	13.00	10.00	30.00
	2,4 D undiluted injection (0.017 oz/in. DBH) (1 ml/2.54 cm)	Herbaceous	Herbaceous	Biomass (dry)	3	288.40	252.50	14.22
	2,4 D undiluted injection (0.017 oz/in. DBH) (1 ml/2.54 cm)	Green biomass	Total	Biomass (dry)	3	1662.90	910.20	82.70
	2,4 D undiluted injection (0.017 oz/in. DBH) (1 ml/2.54 cm)	Shrubs	Woody	Biomass (dry)	3	1027.00	321.80	219.14
	2,4 D undiluted injection (0.017 oz/in. DBH) (1 ml/2.54 cm)	Trees (understory)	Woody	Biomass (dry)	3	131.40	143.50	-8.43
	2,4 D undiluted injection (0.017 oz/in. DBH) (1 ml/2.54 cm)	Woody vines	Woody vines	Biomass (dry)	3	216.10	192.40	12.32
Provencher et al. 2000b	Hexazinone (ULW) (1.5 lbs ai/ac) (1.68 kg ai/ha)	Total (1996)	Total	Species richness	6	40.06	41.58	-3.66
	Hexazinone (ULW) (1.5 lbs ai/ac) (1.68 kg ai/ha)	Total (1998)	Total	Species richness	6	49.04	42.90	14.31
	Hexazinone (ULW) (1.5 lbs ai/ac) (1.68 kg ai/ha)	Graminoids (1996)	Graminoids	Density	6	3.73	4.61	-19.09
	Hexazinone (ULW) (1.5 lbs ai/ac) (1.68 kg ai/ha)	Graminoids (1998)	Graminoids	Density	6	7.21	4.21	71.26
	Hexazinone (ULW) (1.5 lbs ai/ac) (1.68 kg ai/ha)	Forbs (1996)	Herbaceous	Density	6	4.75	4.09	16.14
	Hexazinone (ULW) (1.5 lbs ai/ac) (1.68 kg ai/ha)	Forbs (1998)	Herbaceous	Density	6	6.35	3.27	94.19

Study	*Herbicide*	*Group*	*Category*	*Response variable*	*N*	*Treatment*	*Control*	*% change*
	Hexazinone (ULW) (1.5 lbs ai/ac) (1.68 kg ai/ha)	Legumes (1996)	Herbaceous	Density	6	0.97	1.67	-41.92
	Hexazinone (ULW) (1.5 lbs ai/ac) (1.68 kg ai/ha)	Legumes (1998)	Herbaceous	Density	6	1.29	1.38	-6.52
	Hexazinone (ULW) (1.5 lbs ai/ac) (1.68 kg ai/ha)	Shrubs (1996)	Woody	Density	6	10.43	13.39	-22.11
	Hexazinone (ULW) (1.5 lbs ai/ac) (1.68 kg ai/ha)	Shrubs (1998)	Woody	Density	6	8.89	11.70	-24.02
	Hexazinone (ULW) (1.5 lbs ai/ac) (1.68 kg ai/ha)	Woody vines (1996)	Woody vines	Density	6	1.83	2.11	-13.27
	Hexazinone (ULW) (1.5 lbs ai/ac) (1.68 kg ai/ha)	Woody vines (1998)	Woody vines	Density	6	1.51	1.77	-14.69
Provencher et al., *unpublished data*	Hexazinone (ULW) (1.5 lbs ai/ac) (1.68 kg ai/ha)	Graminoids (1996)	Graminoids	Cover	6	0.05	0.03	66.67
	Hexazinone (ULW) (1.5 lbs ai/ac) (1.68 kg ai/ha)	Graminoids (1998)	Graminoids	Cover	6	0.15	0.04	275.00
	Hexazinone (ULW) (1.5 lbs ai/ac) (1.68 kg ai/ha)	Forbs (1996)	Herbaceous	Cover	6	0.06	0.04	50.00
	Hexazinone (ULW) (1.5 lbs ai/ac) (1.68 kg ai/ha)	Forbs (1998)	Herbaceous	Cover	6	0.10	0.04	150.00
	Hexazinone (ULW) (1.5 lbs ai/ac) (1.68 kg ai/ha)	Woody (1996)	Woody	Cover	6	0.08	0.12	-33.33
	Hexazinone (ULW) (1.5 lbs ai/ac) (1.68 kg ai/ha)	Woody (1998)	Woody	Cover	6	0.12	0.15	-20.00
Wilkins et al. 1993a	Hexazinone (Pronone 10G) (1.52 lbs ai/ac) (1.7 kg ai/ha)	Herbaceous (yr 1)	Herbaceous	Species richness	3	7.50	19.90	-62.31
	Hexazinone (Pronone 10G) (1.52 lbs ai/ac) (1.7 kg ai/ha)	Herbaceous (yr 2)	Herbaceous	Species richness	3	22.30	25.20	-11.51
	Hexazinone (Pronone 10G) (1.52 lbs ai/ac) (1.7 kg ai/ha)	Woody (yr 1)	Woody	Species richness	3	10.90	14.50	-24.83
	Hexazinone (Pronone 10G) (1.52 lbs ai/ac) (1.7 kg ai/ha)	Woody (yr 2)	Woody	Species richness	3	14.60	16.30	-10.43

Study	Herbicide	Group	Category	Response variable	N	Treatment	Control	% change
	Hexazinone (Pronone 10G) (3.03 lbs ai/ac) (3.4 kg ai/ha)	Herbaceous (yr 1)	Herbaceous	Species richness	3	1.70	19.90	-91.46
	Hexazinone (Pronone 10G) (3.03 lbs ai/ac) (3.4 kg ai/ha)	Herbaceous (yr 2)	Herbaceous	Species richness	3	18.30	25.20	-27.38
	Hexazinone (Pronone 10G) (3.03 lbs ai/ac) (3.4 kg ai/ha)	Woody (yr 1)	Woody	Species richness	3	6.90	14.50	-52.41
	Hexazinone (Pronone 10G) (3.03 lbs ai/ac) (3.4 kg ai/ha)	Woody (yr 2)	Woody	Species richness	3	9.90	16.30	-39.26
	Hexazinone (Pronone 10G) (6.07 lbs ai/ac) (6.8 kg ai/ha)	Herbaceous (yr 1)	Herbaceous	Species richness	3	1.30	19.90	-93.47
	Hexazinone (Pronone 10G) (6.07 lbs ai/ac) (6.8 kg ai/ha)	Herbaceous (yr 2)	Herbaceous	Species richness	3	13.90	25.20	-44.84
	Hexazinone (Pronone 10G) (6.07 lbs ai/ac) (6.8 kg ai/ha)	Woody (yr 1)	Woody	Species richness	3	4.30	14.50	-70.34
	Hexazinone (Pronone 10G) (6.07 lbs ai/ac) (6.8 kg ai/ha)	Woody (yr 2)	Woody	Species richness	3	6.50	16.30	-60.12
	Hexazinone (Pronone 10G) (1.52 lbs ai/ac) (1.7 kg ai/ha)	Herbaceous (yr 1)	Herbaceous	Cover	3	15.40	51.30	-69.98
	Hexazinone (Pronone 10G) (1.52 lbs ai/ac) (1.7 kg ai/ha)	Herbaceous (yr 2)	Herbaceous	Cover	3	51.30	46.10	11.28
	Hexazinone (Pronone 10G) (1.52 lbs ai/ac) (1.7 kg ai/ha)	Woody (yr 1)	Woody	Cover	3	22.70	32.20	-29.50
	Hexazinone (Pronone 10G) (1.52 lbs ai/ac) (1.7 kg ai/ha)	Woody (yr 2)	Woody	Cover	3	42.00	47.70	-11.95
	Hexazinone (Pronone 10G) (3.03 lbs ai/ac) (3.4 kg ai/ha)	Herbaceous (yr 1)	Herbaceous	Cover	3	0.80	51.30	-98.44
	Hexazinone (Pronone 10G) (3.03 lbs ai/ac) (3.4 kg ai/ha)	Herbaceous (yr 2)	Herbaceous	Cover	3	60.10	46.10	30.37
	Hexazinone (Pronone 10G) (3.03 lbs ai/ac) (3.4 kg ai/ha)	Woody (yr 1)	Woody	Cover	3	8.10	32.20	-74.84
	Hexazinone (Pronone 10G) (3.03 lbs ai/ac) (3.4 kg ai/ha)	Woody (yr 2)	Woody	Cover	3	19.40	47.70	-59.33

Study	*Herbicide*	*Group*	*Category*	*Response variable*	*N*	*Treatment*	*Control*	*% change*
	Hexazinone (Pronone 10G) (6.07 lbs ai/ac) (6.8 kg ai/ha)	Herbaceous (yr 1)	Herbaceous	Cover	3	1.10	51.30	-97.86
	Hexazinone (Pronone 10G) (6.07 lbs ai/ac) (6.8 kg ai/ha)	Herbaceous (yr 2)	Herbaceous	Cover	3	58.40	46.10	26.68
	Hexazinone (Pronone 10G) (6.07 lbs ai/ac) (6.8 kg ai/ha)	Woody (yr 1)	Woody	Cover	3	7.10	32.20	-77.95
	Hexazinone (Pronone 10G) (6.07 lbs ai/ac) (6.8 kg ai/ha)	Woody (yr 2)	Woody	Cover	3	8.70	47.70	-81.76
Wilkins et al. 1993b	Hexazinone (Velpar L) (0.37 lbs ai/ac) (0.42 kg ai/ha)	Grasses	Graminoids	Cover	3	0.74	0.11	572.73
	Hexazinone (Velpar L) (0.37 lbs ai/ac) (0.42 kg ai/ha)	Forbs	Herbaceous	Cover	3	2.10	3.30	-36.36
	Hexazinone (Velpar L) (0.37 lbs ai/ac) (0.42 kg ai/ha)	Other woody	Woody	Cover	3	0.85	0.40	112.50
	Hexazinone (Velpar L) (0.75 lbs ai/ac) (0.84 kg ai/ha)	Grasses	Graminoids	Cover	3	0.80	0.11	627.27
	Hexazinone (Velpar L) (0.75 lbs ai/ac) (0.84 kg ai/ha)	Forbs	Herbaceous	Cover	3	0.99	3.30	-70.00
	Hexazinone (Velpar L) (0.75 lbs ai/ac) (0.84 kg ai/ha)	Other woody	Woody	Cover	3	0.32	0.40	-20.00
	Hexazinone (Velpar L) (1.5 lbs ai/ac) (1.68 kg ai/ha)	Grasses	Graminoids	Cover	3	3.61	0.11	3181.82
	Hexazinone (Velpar L) (1.5 lbs ai/ac) (1.68 kg ai/ha)	Forbs	Herbaceous	Cover	3	0.59	3.30	-82.12
	Hexazinone (Velpar L) (1.5 lbs ai/ac) (1.68 kg ai/ha)	Other woody	Woody	Cover	3	-0.12	0.40	-130.00
PINE PLANTATIONS								
Blake 1986	Hexazinone (Pronone 5G) (1 lb ai/ac) (1.12 kg ai/ha)	Total (yr 1)	Total	Species richness	5	59.00	106.00	-44.34
	Hexazinone (Pronone 5G) (1 lb ai/ac) (1.12 kg ai/ha)	Total (yr 1)	Total	Biomass	5	1199.00	2816.00	-57.42

Study	*Herbicide*	*Group*	*Category*	*Response variable*	*N*	*Treatment*	*Control*	*% change*
	Hexazinone (Pronone 5G) (1 lb ai/ac) (1.12 kg ai/ha)	Total (yr 2)	Total	Species richness	5	108.00	108.00	0.00
	Hexazinone (Pronone 5G) (1 lb ai/ac) (1.12 kg ai/ha)	Total (yr 2)	Total	Biomass	5	3575.00	3414.00	4.72
	Hexazinone (Velpar L) (1 lb ai/ac) (1.12 kg ai/ha)	Total (yr 1)	Total	Biomass	5	1660.00	2816.00	-41.05
	Hexazinone (Velpar L) (1 lb ai/ac) (1.12 kg ai/ha)	Total (yr 2)	Total	Biomass	5	3320.00	3414.00	-2.75
	Hexazinone (Velpar L) (1 lb ai/ac) (1.12 kg ai/ha)	Total (yr 1)	Total	Species richness	5	97.00	106.00	-8.49
	Hexazinone (Velpar L) (1 lb ai/ac) (1.12 kg ai/ha)	Total (yr 2)	Total	Species richness	5	100.00	108.00	-7.41
Boyd et al. 1995	Glyphosate (Roundup) (1.52 lbs ae/ac) (1.7 kg ae/ha)	Grass-Grasslike	Graminoids	Species richness	3	9.30	9.00	3.33
	Glyphosate (Roundup) (1.52 lbs ae/ac) (1.7 kg ae/ha)	Forbs	Herbaceous	Species richness	3	29.00	20.00	45.00
	Glyphosate (Roundup) (1.52 lbs ae/ac) (1.7 kg ae/ha)	Legume	Herbaceous	Species richness	3	7.30	6.30	15.87
	Glyphosate (Roundup) (1.52 lbs ae/ac) (1.7 kg ae/ha)	Total	Total	Species richness	3	83.00	75.00	10.67
	Glyphosate (Roundup) (1.52 lbs ae/ac) (1.7 kg ae/ha)	Arborescent	Woody	Species richness	3	16.00	21.00	-23.81
	Glyphosate (Roundup) (1.52 lbs ae/ac) (1.7 kg ae/ha)	Nonarborescent	Woody	Species richness	3	9.00	11.00	-18.18
	Glyphosate (Roundup) (1.52 lbs ae/ac) (1.7 kg ae/ha)	Woody vines	Woody vines	Species richness	3	8.70	6.00	45.00
	Hexazinone (Pronone 10G) (site dependent rate) (0.89, 1.52 lbs ai/ac) (1.0, 1.7 kg ai/ha)	Grass-Grasslike	Graminoids	Species richness	3	9.70	9.00	7.78
	Hexazinone (Pronone 10G) (site dependent rate) (0.89, 1.52 lbs ai/ac) (1.0, 1.7 kg ai/ha)	Forbs	Herbaceous	Species richness	3	21.00	20.00	5.00

Study	*Herbicide*	*Group*	*Category*	*Response variable*	*N*	*Treatment*	*Control*	*% change*
	Hexazinone (Pronone 10G) (site dependent rate) (0.89, 1.52 lbs ai/ac) (1.0, 1.7 kg ai/ha)	Legume	Herbaceous	Species richness	3	6.70	6.30	6.35
	Hexazinone (Pronone 10G) (site dependent rate) (0.89, 1.52 lbs ai/ac) (1.0, 1.7 kg ai/ha)	Total	Total	Species richness	3	75.00	75.00	0.00
	Hexazinone (Pronone 10G) (site dependent rate) (0.89, 1.52 lbs ai/ac) (1.0, 1.7 kg ai/ha)	Arborescent	Woody	Species richness	3	19.00	21.00	-9.52
	Hexazinone (Pronone 10G) (site dependent rate) (0.89, 1.52 lbs ai/ac) (1.0, 1.7 kg ai/ha)	Nonarborescent	Woody	Species richness	3	11.00	11.00	0.00
	Hexazinone (Pronone 10G) (site dependent rate) (0.89, 1.52 lbs ai/ac) (1.0, 1.7 kg ai/ha)	Woody vines	Woody vines	Species richness	3	6.30	6.00	5.00
	Hexazinone (Velpar L) (site dependent rate) (0.62, 0.98, 2.23 lbs ai/ac) (0.7, 1.1, 2.5 kg ai/ha)	Grass-Grasslike	Graminoids	Species richness	3	7.70	9.00	-14.44
	Hexazinone (Velpar L) (site dependent rate) (0.62, 0.98, 2.23 lbs ai/ac) (0.7, 1.1, 2.5 kg ai/ha)	Forbs	Herbaceous	Species richness	3	20.00	20.00	0.00
	Hexazinone (Velpar L) (site dependent rate) (0.62, 0.98, 2.23 lbs ai/ac) (0.7, 1.1, 2.5 kg ai/ha)	Legume	Herbaceous	Species richness	3	8.00	6.30	26.98
	Hexazinone (Velpar L) (site dependent rate) (0.62, 0.98, 2.23 lbs ai/ac) (0.7, 1.1, 2.5 kg ai/ha)	Total	Total	Species richness	3	72.00	75.00	-4.00
	Hexazinone (Velpar L) (site dependent rate) (0.62, 0.98, 2.23 lbs ai/ac) (0.7, 1.1, 2.5 kg ai/ha)	Arborescent	Woody	Species richness	3	18.00	21.00	-14.29
	Hexazinone (Velpar L) (site dependent rate) (0.62, 0.98, 2.23 lbs ai/ac) (0.7, 1.1, 2.5 kg ai/ha)	Nonarborescent	Woody	Species richness	3	10.00	11.00	-9.09

Study	*Herbicide*	*Group*	*Category*	*Response variable*	*N*	*Treatment*	*Control*	*% change*
	Hexazinone (Velpar L) (site dependent rate) (0.62, 0.98, 2.23 lbs ai/ac) (0.7, 1.1, 2.5 kg ai/ha)	Woody vines	Woody vines	Species richness	3	6.30	6.00	5.00
	Imazapyr (Arsenal) (0.98 lbs ae/ac) (1.1 kg ae/ha)	Grass-Grasslike	Graminoids	Species richness	3	8.70	9.00	-3.33
	Imazapyr (Arsenal) (0.98 lbs ae/ac) (1.1 kg ae/ha)	Forbs	Herbaceous	Species richness	3	20.00	20.00	0.00
	Imazapyr (Arsenal) (0.98 lbs ae/ac) (1.1 kg ae/ha)	Legume	Herbaceous	Species richness	3	8.00	6.30	26.98
	Imazapyr (Arsenal) (0.98 lbs ae/ac) (1.1 kg ae/ha)	Total	Total	Species richness	3	73.00	75.00	-2.67
	Imazapyr (Arsenal) (0.98 lbs ae/ac) (1.1 kg ae/ha)	Arborescent	Woody	Species richness	3	17.00	21.00	-19.05
	Imazapyr (Arsenal) (0.98 lbs ae/ac) (1.1 kg ae/ha)	Nonarborescent	Woody	Species richness	3	9.30	11.00	-15.45
	Imazapyr (Arsenal) (0.98 lbs ae/ac) (1.1 kg ae/ha)	Woody vines	Woody vines	Species richness	3	8.00	6.00	33.33
	Glyphosate (Roundup) (1.52 lbs ae/ac) (1.7 kg ae/ha)	Understory	Total	Simpson diversity	3	0.90	0.92	-2.17
	Hexazinone (Pronone 10G) (site dependent rate) (0.89, 1.52 lbs ai/ac) (1.0, 1.7 kg ai/ha)	Understory	Total	Simpson diversity	3	0.91	0.92	-1.09
	Hexazinone (Velpar L) (site dependent rate) (0.62, 0.98, 2.23 lbs ai/ac) (0.7, 1.1, 2.5 kg ai/ha)	Understory	Total	Simpson diversity	3	0.84	0.92	-8.70
	Imazapyr (Arsenal) (0.98 lbs ae/ac) (1.1 kg ae/ha)	Understory	Total	Simpson diversity	3	0.83	0.92	-9.78
	Glyphosate (Roundup) (1.52 lbs ae/ac) (1.7 kg ae/ha)	Understory	Total	Shannon diversity	3	4.30	4.00	7.50
	Hexazinone (Pronone 10G) (site dependent rate) (0.89, 1.52 lbs ai/ac) (1.0, 1.7 kg ai/ha)	Understory	Total	Shannon diversity	3	4.30	4.00	7.50

Study	*Herbicide*	*Group*	*Category*	*Response variable*	*N*	*Treatment*	*Control*	*% change*
	Hexazinone (Velpar L) (site dependent rate) (0.62, 0.98, 2.23 lbs ai/ac) (0.7, 1.1, 2.5 kg ai/ha)	Understory	Total	Shannon diversity	3	3.60	4.00	-10.00
	Imazapyr (Arsenal) (0.98 lbs ae/ac) (1.1 kg ae/ha)	Understory	Total	Shannon diversity	3	3.70	4.00	-7.50
	Glyphosate (Roundup) (1.52 lbs ae/ac) (1.7 kg ae/ha)	Grass-Grasslike	Graminoids	Importance value	3	13.10	8.60	52.33
	Glyphosate (Roundup) (1.52 lbs ae/ac) (1.7 kg ae/ha)	Fern	Herbaceous	Importance value	3	0.30	0.50	-40.00
	Glyphosate (Roundup) (1.52 lbs ae/ac) (1.7 kg ae/ha)	Forbs	Herbaceous	Importance value	3	27.80	18.90	47.09
	Glyphosate (Roundup) (1.52 lbs ae/ac) (1.7 kg ae/ha)	Legumes	Herbaceous	Importance value	3	7.60	6.20	22.58
	Glyphosate (Roundup) (1.52 lbs ae/ac) (1.7 kg ae/ha)	Arborescent	Woody	Importance value	3	16.40	21.40	-23.36
	Glyphosate (Roundup) (1.52 lbs ae/ac) (1.7 kg ae/ha)	Nonarborescent	Woody	Importance value	3	11.20	25.20	-55.56
	Glyphosate (Roundup) (1.52 lbs ae/ac) (1.7 kg ae/ha)	Semiwoody	Woody	Importance value	3	6.00	3.70	62.16
	Glyphosate (Roundup) (1.52 lbs ae/ac) (1.7 kg ae/ha)	Woody vine	Woody vines	Importance value	3	23.40	22.10	5.88
	Hexazinone (Pronone 10G) (site dependent rate) (0.89, 1.52 lbs ai/ac) (1.0, 1.7 kg ai/ha)	Grass-Grasslike	Graminoids	Importance value	3	10.30	8.60	19.77
	Hexazinone (Pronone 10G) (site dependent rate) (0.89, 1.52 lbs ai/ac) (1.0, 1.7 kg ai/ha)	Fern	Herbaceous	Importance value	3	0.40	0.50	-20.00
	Hexazinone (Pronone 10G) (site dependent rate) (0.89, 1.52 lbs ai/ac) (1.0, 1.7 kg ai/ha)	Forbs	Herbaceous	Importance value	3	24.00	18.90	26.98
	Hexazinone (Pronone 10G) (site dependent rate) (0.89, 1.52 lbs ai/ac) (1.0, 1.7 kg ai/ha)	Legumes	Herbaceous	Importance value	3	6.20	6.20	0.00

Study	*Herbicide*	*Group*	*Category*	*Response variable*	*N*	*Treatment*	*Control*	*% change*
	Hexazinone (Pronone 10G) (site dependent rate) (0.89, 1.52 lbs ai/ac) (1.0, 1.7 kg ai/ha)	Arborescent	Woody	Importance value	3	12.10	21.40	-43.46
	Hexazinone (Pronone 10G) (site dependent rate) (0.89, 1.52 lbs ai/ac) (1.0, 1.7 kg ai/ha)	Semiwoody	Woody	Importance value	3	4.20	3.70	13.51
	Hexazinone (Pronone 10G) (site dependent rate) (0.89, 1.52 lbs ai/ac) (1.0, 1.7 kg ai/ha)	Woody vine	Woody vines	Importance value	3	25.60	22.10	15.84
	Hexazinone (Pronone 10G) (site dependent rate) (0.89, 1.52 lbs ai/ac) (1.0, 1.7 kg ai/ha)	Nonarborescent	Woody	Importance value	3	23.40	25.20	-7.14
	Hexazinone (Velpar L) (site dependent rate) (0.62, 0.98, 2.23 lbs ai/ac) (0.7, 1.1, 2.5 kg ai/ha)	Grass-Grasslike	Graminoids	Importance value	3	15.70	8.60	82.56
	Hexazinone (Velpar L) (site dependent rate) (0.62, 0.98, 2.23 lbs ai/ac) (0.7, 1.1, 2.5 kg ai/ha)	Fern	Herbaceous	Importance value	3	0.10	0.50	-80.00
	Hexazinone (Velpar L) (site dependent rate) (0.62, 0.98, 2.23 lbs ai/ac) (0.7, 1.1, 2.5 kg ai/ha)	Forbs	Herbaceous	Importance value	3	21.30	18.90	12.70
	Hexazinone (Velpar L) (site dependent rate) (0.62, 0.98, 2.23 lbs ai/ac) (0.7, 1.1, 2.5 kg ai/ha)	Legumes	Herbaceous	Importance value	3	5.70	6.20	-8.06
	Hexazinone (Velpar L) (site dependent rate) (0.62, 0.98, 2.23 lbs ai/ac) (0.7, 1.1, 2.5 kg ai/ha)	Arborescent	Woody	Importance value	3	12.40	21.40	-42.06
	Hexazinone (Velpar L) (site dependent rate) (0.62, 0.98, 2.23 lbs ai/ac) (0.7, 1.1, 2.5 kg ai/ha)	Semiwoody	Woody	Importance value	3	3.70	3.70	0.00
	Hexazinone (Velpar L) (site dependent rate) (0.62, 0.98, 2.23 lbs ai/ac) (0.7, 1.1, 2.5 kg ai/ha)	Woody vine	Woody vines	Importance value	3	23.20	22.10	4.98

Study	Herbicide	Group	Category	Response variable	N	Treatment	Control	% change
	Hexazinone (Velpar L) (site dependent rate) (0.62, 0.98, 2.23 lbs ai/ac) (0.7, 1.1, 2.5 kg ai/ha)	Nonarborescent	Woody	Importance value	3	23.80	25.20	-5.56
	Imazapyr (Arsenal) (0.98 lbs ae/ac) (1.1 kg ae/ha)	Grass-Grasslike	Graminoids	Importance value	3	11.20	8.60	30.23
	Imazapyr (Arsenal) (0.98 lbs ae/ac) (1.1 kg ae/ha)	Fern	Herbaceous	Importance value	3	0.70	0.50	40.00
	Imazapyr (Arsenal) (0.98 lbs ae/ac) (1.1 kg ae/ha)	Forbs	Herbaceous	Importance value	3	25.50	18.90	34.92
	Imazapyr (Arsenal) (0.98 lbs ae/ac) (1.1 kg ae/ha)	Legumes	Herbaceous	Importance value	3	10.00	6.20	61.29
	Imazapyr (Arsenal) (0.98 lbs ae/ac) (1.1 kg ae/ha)	Arborescent	Woody	Importance value	3	14.10	21.40	-34.11
	Imazapyr (Arsenal) (0.98 lbs ae/ac) (1.1 kg ae/ha)	Nonarborescent	Woody	Importance value	3	14.90	25.20	-40.87
	Imazapyr (Arsenal) (0.98 lbs ae/ac) (1.1 kg ae/ha)	Semiwoody	Woody	Importance value	3	12.30	3.70	232.43
	Imazapyr (Arsenal) (0.98 lbs ae/ac) (1.1 kg ae/ha)	Woody vine	Woody vines	Importance value	3	21.30	22.10	-3.62
	Glyphosate (Roundup) (1.52 lbs ae/ac) (1.7 kg ae/ha)	Nonarborescent	Woody	Density (/ha)	3	700.00	3300.00	-78.79
	Hexazinone (Pronone 10G) (site dependent rate) (0.89, 1.52 lbs ai/ac) (1.0, 1.7 kg ai/ha)	Nonarborescent	Woody	Density (/ha)	3	2700.00	3300.00	-18.18
	Hexazinone (Velpar L) (site dependent rate) (0.62, 0.98, 2.23 lbs ai/ac) (0.7, 1.1, 2.5 kg ai/ha)	Nonarborescent	Woody	Density (/ha)	3	4500.00	3300.00	36.36
	Imazapyr (Arsenal) (0.98 lbs ae/ac) (1.1 kg ae/ha)	Nonarborescent	Woody	Density (/ha)	3	1300.00	3300.00	-60.61
Clewell & Lasley 1998 (Trial 1)	Triclopyr (Garlon 4) (0.4%)	Graminoids (mo. 7)	Graminoids	Frequency	3	-0.38	-0.26	46.15
	Triclopyr (Garlon 4) (0.4%)	Graminoids (mo. 12)	Graminoids	Frequency	3	-0.21	-0.01	2033.33
	Triclopyr (Garlon 4) (0.4%)	Forbs (mo. 7)	Herbaceous	Frequency	3	-0.29	1.95	-114.87
	Triclopyr (Garlon 4) (0.4%)	Forbs (mo. 12)	Herbaceous	Frequency	3	1.67	2.00	-16.50

Study	*Herbicide*	*Group*	*Category*	*Response variable*	*N*	*Treatment*	*Control*	*% change*
	Triclopyr (Garlon 4) (0.4%)	Shrubs & vines (mo. 7)	Woody	Frequency	3	-0.80	-0.03	2566.67
	Triclopyr (Garlon 4) (0.4%)	Shrubs & vines (mo. 12)	Woody	Frequency	3	-0.60	-0.02	2900.00
Clewell & Lasley 1998 (Trial 3)	Triclopyr (Garlon 4) (0.4%)	Graminoids (mo. 7)	Graminoids	Frequency	3	-0.57	-0.39	46.15
	Triclopyr (Garlon 4) (0.4%)	Graminoids (mo. 12)	Graminoids	Frequency	3	-0.18	-0.39	-53.85
	Triclopyr (Garlon 4) (0.4%)	Forbs (mo. 7)	Herbaceous	Frequency	3	-0.37	0.72	-151.39
	Triclopyr (Garlon 4) (0.4%)	Forbs (mo. 12)	Herbaceous	Frequency	3	-0.07	-0.09	-22.22
	Triclopyr (Garlon 4) (0.4%)	Shrubs & vines (mo. 7)	Woody	Frequency	3	-0.62	0.15	-513.33
	Triclopyr (Garlon 4) (0.4%)	Shrubs & vines (mo. 12)	Woody	Frequency	3	-0.52	0.17	-405.88
Harrington & Edwards 1999	Hexazinone (Velpar) (1.52 lbs ai/ac) (1.7 kg ai/ha) + triclopyr ester (7% in oil) + imazapyr (0.5%) + glyphosate (5%)	Herbaceous (1998)	Herbaceous	Species richness	6	30.00	25.00	20.00
	Hexazinone (Velpar) (1.52 lbs ai/ac) (1.7 kg ai/ha) + triclopyr ester (7% in oil) + imazapyr (0.5%) + glyphosate (5%)	Total species (1995)	Total	Density	6	-0.11	-0.10	10.00
	Hexazinone (Velpar) (1.52 lbs ai/ac) (1.7 kg ai/ha) + triclopyr ester (7% in oil) + imazapyr (0.5%) + glyphosate (5%)	Total species (1998)	Total	Density	6	0.28	0.09	211.11
	Hexazinone (Velpar) (1.52 lbs ai/ac) (1.7 kg ai/ha) + triclopyr ester (7% in oil) + imazapyr (0.5%) + glyphosate (5%)	Grass (1995)	Graminoids	Cover	6	-0.03	-0.11	-72.73
	Hexazinone (Velpar) (1.52 lbs ai/ac) (1.7 kg ai/ha) + triclopyr ester (7% in oil) + imazapyr (0.5%) + glyphosate (5%)	Grass (1998)	Graminoids	Cover	6	0.22	-0.41	-153.66

Study	*Herbicide*	*Group*	*Category*	*Response variable*	*N*	*Treatment*	*Control*	*% change*
	Hexazinone (Velpar) (1.52 lbs ai/ac) (1.7 kg ai/ha) + triclopyr ester (7% in oil) + imazapyr (0.5%) + glyphosate (5%)	Forb (1995)	Herbaceous	Cover	6	-0.27	-0.20	35.00
	Hexazinone (Velpar) (1.52 lbs ai/ac) (1.7 kg ai/ha) + triclopyr ester (7% in oil) + imazapyr (0.5%) + glyphosate (5%)	Forb (1998)	Herbaceous	Cover	6	-0.22	-0.32	-31.25
	Hexazinone (Velpar) (1.52 lbs ai/ac) (1.7 kg ai/ha) + triclopyr ester (7% in oil) + imazapyr (0.5%) + glyphosate (5%)	Shrub (1995)	Woody	Cover	6	-0.11	0.19	-157.89
	Hexazinone (Velpar) (1.52 lbs ai/ac) (1.7 kg ai/ha) + triclopyr ester (7% in oil) + imazapyr (0.5%) + glyphosate (5%)	Shrub (1998)	Woody	Cover	6	-0.78	-0.29	168.97
	Hexazinone (Velpar) (1.52 lbs ai/ac) (1.7 kg ai/ha) + triclopyr ester (7% in oil) + imazapyr (0.5%) + glyphosate (5%)	Vine (1995)	Woody vines	Cover	6	-0.40	-0.35	14.29
	Hexazinone (Velpar) (1.52 lbs ai/ac) (1.7 kg ai/ha) + triclopyr ester (7% in oil) + imazapyr (0.5%) + glyphosate (5%)	Vine (1998)	Woody vines	Cover	6	-0.55	-0.16	243.75
Haywood et al. 1997	Hexazinone (ULW) (1 lb/ac) (1.12 kg/ha) + sulfometuron (0.19 lbs/ac) (0.21 kg/ha) + glyphosate (1%) + glyphosate (1.38 lbs/ac) (1.55 kg/ha) + sulfometuron (0.35 lbs/ac) (0.39 kg/ha)	Herbaceous	Herbaceous	Biomass (dry)	3	97.00	2071.00	-95.32
	Hexazinone (ULW) (1 lb/ac) (1.12 kg/ha) + sulfometuron (0.19 lbs/ac) (0.21 kg/ha) + glyphosate (1%) + glyphosate (1.38 lbs/ac) (1.55 kg/ha) + sulfometuron (0.35 lbs/ac) (0.39 kg/ha)	Other shrubs	Woody	Density (/ha)	3	850.00	4900.00	-82.65

Study	*Herbicide*	*Group*	*Category*	*Response variable*	*N*	*Treatment*	*Control*	*% change*
	Hexazinone (ULW) (1 lb/ac) (1.12 kg/ha) + sulfometuron (0.19 lbs/ac) (0.21 kg/ha) + glyphosate (1%) + glyphosate (1.38 lbs/ac) (1.55 kg/ha) + sulfometuron (0.35 lbs/ac) (0.39 kg/ha)	Vines	Woody vines	Density (/ha)	3	3417.00	2517.00	35.76
Hurst & Blake 1987	Hexazinone (Pronone 5G) (1 lb ai/ac) (1.12 kg ai/ha)	Total	Total	Species richness	5	84.50	106.00	-20.28
	Hexazinone (Velpar) (1 lb/ac) (1 lb ai/ac) (1.12 kg ai/ha)	Total	Total	Species richness	5	98.50	106.00	-7.08
Lauer & Glover 1998	Sulfometuron (3 oz ai/ac) (0.44 L ai/ha) + glyphosate (1-2%)	Herbaceous (yr 1)	Herbaceous	Cover	10	25.00	43.00	-41.86
	Sulfometuron (3 oz ai/ac) (0.44 L ai/ha) + glyphosate (1-2%)	Herbaceous (yr 5)	Herbaceous	Cover	10	44.00	37.00	18.92
	Sulfometuron (3 oz ai/ac) (0.44 L ai/ha) + glyphosate (1-2%)	Shrub (yr 1)	Woody	Cover	10	25.00	27.00	-7.41
	Sulfometuron (3 oz ai/ac) (0.44 L ai/ha) + glyphosate (1-2%)	Shrub (yr 5)	Woody	Cover	10	57.00	62.00	-8.06
	Triclopyr (Garlon) (4-5 lbs ae/ac in 20-30 gal) (4.48-5.60 kg ae/ha in 75.7-113.6 L)	Herbaceous (yr 1)	Herbaceous	Cover	10	47.00	43.00	9.30
	Triclopyr (Garlon) (4-5 lbs ae/ac in 20-30 gal) (4.48-5.60 kg ae/ha in 75.7-113.6 L)	Herbaceous (yr 5)	Herbaceous	Cover	10	66.00	37.00	78.38
	Triclopyr (Garlon) (4-5 lbs ae/ac in 20-30 gal) (4.48-5.60 kg ae/ha in 75.7-113.6 L)	Shrub (yr 1)	Woody	Cover	10	5.00	27.00	-81.48
	Triclopyr (Garlon) (4-5 lbs ae/ac in 20-30 gal) (4.48-5.60 kg ae/ha in 75.7-113.6 L)	Shrub (yr 5)	Woody	Cover	10	29.00	62.00	-53.23
	Triclopyr (4-5 lbs ae/ac in 20-30 gal) (4.48-5.60 kg ae/ha in 75.7-113.6 L) + sulfometuron (3 oz ai/ac) (0.44 L ai/ha) + glyphosate (1-2%)	Herbaceous (yr 1)	Herbaceous	Cover	10	17.00	43.00	-60.47

Study	*Herbicide*	*Group*	*Category*	*Response variable*	*N*	*Treatment*	*Control*	*% change*
	Triclopyr (4-5 lbs ae/ac in 20-30 gal) (4.48-5.60 kg ae/ha in 75.7-113.6 L) + sulfometuron (3 oz ai/ac) (0.44 L ai/ha) + glyphosate (1-2%)	Herbaceous (yr 5)	Herbaceous	Cover	10	71.00	37.00	91.89
	Triclopyr (4-5 lbs ae/ac in 20-30 gal) (4.48-5.60 kg ae/ha in 75.7-113.6 L) + sulfometuron (3 oz ai/ac) (0.44 L ai/ha) + glyphosate (1-2%)	Shrub (yr 1)	Woody	Cover	10	5.00	27.00	-81.48
	Triclopyr (4-5 lbs ae/ac in 20-30 gal) (4.48-5.60 kg ae/ha in 75.7-113.6 L) + sulfometuron (3 oz ai/ac) (0.44 L ai/ha) + glyphosate (1-2%)	Shrub (yr 5)	Woody	Cover	10	25.00	62.00	-59.68
	Triclopyr (4-5 lbs ae/ac in 20-30 gal) (4.48-5.60 kg ae/ha in 75.7-113.6 L) + triclopyr (6%) + [triclopyr (5%)+ glyphosate (2%)]	Herbaceous (yr 1)	Herbaceous	Cover	10	54.00	43.00	25.58
	Triclopyr (4-5 lbs ae/ac in 20-30 gal) (4.48-5.60 kg ae/ha in 75.7-113.6 L) + triclopyr (6%) + [triclopyr (5%)+ glyphosate (2%)]	Herbaceous (yr 5)	Herbaceous	Cover	10	80.00	37.00	116.22
	Triclopyr (4-5 lbs ae/ac in 20-30 gal) (4.48-5.60 kg ae/ha in 75.7-113.6 L) + triclopyr (6%) + [triclopyr (5%)+ glyphosate (2%)]	Shrub (yr 1)	Woody	Cover	10	4.00	27.00	-85.19
	Triclopyr (4-5 lbs ae/ac in 20-30 gal) (4.48-5.60 kg ae/ha in 75.7-113.6 L) + triclopyr (6%) + [triclopyr (5%)+ glyphosate (2%)]	Shrub (yr 5)	Woody	Cover	10	20.00	62.00	-67.74
	Triclopyr (4-5 lbs ae/ac in 20-30 gal) (4.48-5.60 kg ae/ha in 75.7-113.6 L) + triclopyr (6%) + [triclopyr (5%)+ glyphosate (2%)] + sulfometuron (3 oz ai/ac) (0.44 L ai/ha) + glyphosate (1-2%)	Herbaceous (yr 1)	Herbaceous	Cover	10	20.00	43.00	-53.49

Study	*Herbicide*	*Group*	*Category*	*Response variable*	*N*	*Treatment*	*Control*	*% change*
	Triclopyr (4-5 lbs ae/ac in 20-30 gal) (4.48-5.60 kg ae/ha in 75.7-113.6 L) + triclopyr (6%) + [triclopyr (5%)+ glyphosate (2%)] + sulfometuron (3 oz ai/ac) (0.44 L ai/ha) + glyphosate (1-2%)	Herbaceous (yr 5)	Herbaceous	Cover	10	80.00	37.00	116.22
	Triclopyr (4-5 lbs ae/ac in 20-30 gal) (4.48-5.60 kg ae/ha in 75.7-113.6 L) + triclopyr (6%) + [triclopyr (5%)+ glyphosate (2%)] + sulfometuron (3 oz ai/ac) (0.44 L ai/ha) + glyphosate (1-2%)	Shrub (yr 1)	Woody	Cover	10	8.00	27.00	-70.37
	Triclopyr (4-5 lbs ae/ac in 20-30 gal) (4.48-5.60 kg ae/ha in 75.7-113.6 L) + triclopyr (6%) + [triclopyr (5%)+ glyphosate (2%)] + sulfometuron (3 oz ai/ac) (0.44 L ai/ha) + glyphosate (1-2%)	Shrub (yr 5)	Woody	Cover	10	19.00	62.00	-69.35
Miller et al. 1999	Dicamba + 2,4 D (4.01 lbs ae/ac of each) (4.5 kg ae/ha of each)	Grass-Grasslike	Graminoids	Species richness	4	6.30	6.50	-3.08
	Dicamba + 2,4 D (4.01 lbs ae/ac of each) (4.5 kg ae/ha of each)	All forbs	Herbaceous	Species richness	4	13.30	11.00	20.91
	Dicamba + 2,4 D (4.01 lbs ae/ac of each) (4.5 kg ae/ha of each)	Fern	Herbaceous	Species richness	4	0.30	0.30	0.00
	Dicamba + 2,4 D (4.01 lbs ae/ac of each) (4.5 kg ae/ha of each)	Total	Total	Species richness	4	53.00	55.00	-3.64
	Dicamba + 2,4 D (4.01 lbs ae/ac of each) (4.5 kg ae/ha of each)	Arborescent	Woody	Species richness	4	16.00	19.00	-15.79
	Dicamba + 2,4 D (4.01 lbs ae/ac of each) (4.5 kg ae/ha of each)	Nonarborescent	Woody	Species richness	4	8.00	7.80	2.56
	Dicamba + 2,4 D (4.01 lbs ae/ac of each) (4.5 kg ae/ha of each)	Semiwoody	Woody	Species richness	4	2.30	2.30	0.00
	Dicamba + 2,4 D (4.01 lbs ae/ac of each) (4.5 kg ae/ha of each)	Woody vine	Woody vine	Species richness	4	7.00	8.00	-12.50

Study	*Herbicide*	*Group*	*Category*	*Response variable*	*N*	*Treatment*	*Control*	*% change*
	Glyphosate (Roundup) (3.03 lbs ae/ac) (3.4 kg ae/ha)	Grass-Grasslike	Graminoids	Species richness	4	7.80	6.50	20.00
	Glyphosate (Roundup) (3.03 lbs ae/ac) (3.4 kg ae/ha)	All forbs	Herbaceous	Species richness	4	15.50	11.00	40.91
	Glyphosate (Roundup) (3.03 lbs ae/ac) (3.4 kg ae/ha)	Fern	Herbaceous	Species richness	4	0.50	0.30	66.67
	Glyphosate (Roundup) (3.03 lbs ae/ac) (3.4 kg ae/ha)	Total	Total	Species richness	4	59.00	55.00	7.27
	Glyphosate (Roundup) (3.03 lbs ae/ac) (3.4 kg ae/ha)	Arborescent	Woody	Species richness	4	18.00	19.00	-5.26
	Glyphosate (Roundup) (3.03 lbs ae/ac) (3.4 kg ae/ha)	Nonarborescent	Woody	Species richness	4	8.50	7.80	8.97
	Glyphosate (Roundup) (3.03 lbs ae/ac) (3.4 kg ae/ha)	Semiwoody	Woody	Species richness	4	2.50	2.30	8.70
	Glyphosate (Roundup) (3.03 lbs ae/ac) (3.4 kg ae/ha)	Woody vine	Woody vine	Species richness	4	6.50	8.00	-18.75
	Hexazinone (Pronone 10G) (site dependent rate) (2.5, 3.03, 3.48 lbs ai/ac) (2.8, 3.4, 3.9 kg ai/ha)	Grass-Grasslike	Graminoids	Species richness	4	6.80	6.50	4.62
	Hexazinone (Pronone 10G) (site dependent rate) (2.5, 3.03, 3.48 lbs ai/ac) (2.8, 3.4, 3.9 kg ai/ha)	All forbs	Herbaceous	Species richness	4	17.50	11.00	59.09
	Hexazinone (Pronone 10G) (site dependent rate) (2.5, 3.03, 3.48 lbs ai/ac) (2.8, 3.4, 3.9 kg ai/ha)	Fern	Herbaceous	Species richness	4	0.50	0.30	66.67
	Hexazinone (Pronone 10G) (site dependent rate) (2.5, 3.03, 3.48 lbs ai/ac) (2.8, 3.4, 3.9 kg ai/ha)	Total	Total	Species richness	4	58.00	55.00	5.45
	Hexazinone (Pronone 10G) (site dependent rate) (2.5, 3.03, 3.48 lbs ai/ac) (2.8, 3.4, 3.9 kg ai/ha)	Arborescent	Woody	Species richness	4	16.00	19.00	-15.79
	Hexazinone (Pronone 10G) (site dependent rate) (2.5, 3.03, 3.48 lbs ai/ac) (2.8, 3.4, 3.9 kg ai/ha)	Nonarborescent	Woody	Species richness	4	8.50	7.80	8.97

Study	*Herbicide*	*Group*	*Category*	*Response variable*	*N*	*Treatment*	*Control*	*% change*
	Hexazinone (Pronone 10G) (site dependent rate) (2.5, 3.03, 3.48 lbs ai/ac) (2.8, 3.4, 3.9 kg ai/ha)	Semiwoody	Woody	Species richness	4	2.30	2.30	0.00
	Hexazinone (Pronone 10G) (site dependent rate) (2.5, 3.03, 3.48 lbs ai/ac) (2.8, 3.4, 3.9 kg ai/ha)	Woody vine	Woody vine	Species richness	4	6.80	8.00	-15.00
	Hexazinone (Velpar L) (site dependent rate) (2.5, 3.03, 3.48 lbs ai/ac) (2.8, 3.4, 3.9 kg ai/ha)	Grass-Grasslike	Graminoids	Species richness	4	5.30	6.50	-18.46
	Hexazinone (Velpar L) (site dependent rate) (2.5, 3.03, 3.48 lbs ai/ac) (2.8, 3.4, 3.9 kg ai/ha)	All forbs	Herbaceous	Species richness	4	10.80	11.00	-1.82
	Hexazinone (Velpar L) (site dependent rate) (2.5, 3.03, 3.48 lbs ai/ac) (2.8, 3.4, 3.9 kg ai/ha)	Fern	Herbaceous	Species richness	4	0.50	0.30	66.67
	Hexazinone (Velpar L) (site dependent rate) (2.5, 3.03, 3.48 lbs ai/ac) (2.8, 3.4, 3.9 kg ai/ha)	Total	Total	Species richness	4	50.00	55.00	-9.09
	Hexazinone (Velpar L) (site dependent rate) (2.5, 3.03, 3.48 lbs ai/ac) (2.8, 3.4, 3.9 kg ai/ha)	Arborescent	Woody	Species richness	4	16.00	19.00	-15.79
	Hexazinone (Velpar L) (site dependent rate) (2.5, 3.03, 3.48 lbs ai/ac) (2.8, 3.4, 3.9 kg ai/ha)	Nonarborescent	Woody	Species richness	4	7.80	7.80	0.00
	Hexazinone (Velpar L) (site dependent rate) (2.5, 3.03, 3.48 lbs ai/ac) (2.8, 3.4, 3.9 kg ai/ha)	Semiwoody	Woody	Species richness	4	1.80	2.30	-21.74
	Hexazinone (Velpar L) (site dependent rate) (2.5, 3.03, 3.48 lbs ai/ac) (2.8, 3.4, 3.9 kg ai/ha)	Woody vine	Woody vine	Species richness	4	7.80	8.00	-2.50
	Picloram (3.03 lbs ae/ac) (3.4 kg ae/ha)	Grass-Grasslike	Graminoids	Species richness	4	5.80	6.50	-10.77
	Picloram (3.03 lbs ae/ac) (3.4 kg ae/ha)	All forbs	Herbaceous	Species richness	4	11.30	11.00	2.73

Study	*Herbicide*	*Group*	*Category*	*Response variable*	*N*	*Treatment*	*Control*	*% change*
	Picloram (3.03 lbs ae/ac) (3.4 kg ae/ha)	Fern	Herbaceous	Species richness	4	0.80	0.30	166.67
	Picloram (3.03 lbs ae/ac) (3.4 kg ae/ha)	Total	Total	Species richness	4	53.00	55.00	-3.64
	Picloram (3.03 lbs ae/ac) (3.4 kg ae/ha)	Arborescent	Woody	Species richness	4	17.00	19.00	-10.53
	Picloram (3.03 lbs ae/ac) (3.4 kg ae/ha)	Nonarborescent	Woody	Species richness	4	8.50	7.80	8.97
	Picloram (3.03 lbs ae/ac) (3.4 kg ae/ha)	Semiwoody	Woody	Species richness	4	2.30	2.30	0.00
	Picloram (3.03 lbs ae/ac) (3.4 kg ae/ha)	Woody vine	Woody vine	Species richness	4	7.50	8.00	-6.25
	Triclopyr (Garlon) (3.92 lbs ae/ac) (4.4 kg ae/ha)	Grass-Grasslike	Graminoids	Species richness	4	8.50	6.50	30.77
	Triclopyr (Garlon) (3.92 lbs ae/ac) (4.4 kg ae/ha)	All forbs	Herbaceous	Species richness	4	18.80	11.00	70.91
	Triclopyr (Garlon) (3.92 lbs ae/ac) (4.4 kg ae/ha)	Fern	Herbaceous	Species richness	4	0.50	0.30	66.67
	Triclopyr (Garlon) (3.92 lbs ae/ac) (4.4 kg ae/ha)	Total	Total	Species richness	4	61.00	55.00	10.91
	Triclopyr (Garlon) (3.92 lbs ae/ac) (4.4 kg ae/ha)	Arborescent	Woody	Species richness	4	16.00	19.00	-15.79
	Triclopyr (Garlon) (3.92 lbs ae/ac) (4.4 kg ae/ha)	Nonarborescent	Woody	Species richness	4	8.50	7.80	8.97
	Triclopyr (Garlon) (3.92 lbs ae/ac) (4.4 kg ae/ha)	Semiwoody	Woody	Species richness	4	2.30	2.30	0.00
	Triclopyr (Garlon) (3.92 lbs ae/ac) (4.4 kg ae/ha)	Woody vine	Woody vine	Species richness	4	7.30	8.00	-8.75
	Dicamba + 2,4 D (4.01 lbs ae/ac of each) (4.5 kg ae/ha of each)	Understory	Total	Shannon diversity	4	2.60	2.80	-7.14
	Glyphosate (Roundup) (3.03 lbs ae/ac) (3.4 kg ae/ha)	Understory	Total	Shannon diversity	4	2.80	2.80	0.00

Study	*Herbicide*	*Group*	*Category*	*Response variable*	*N*	*Treatment*	*Control*	*% change*
	Hexazinone (Pronone 10G) (site dependent rate) (2.5, 3.03, 3.48 lbs ai/ac) (2.8, 3.4, 3.9 kg ai/ha)	Understory	Total	Shannon diversity	4	2.70	2.80	-3.57
	Hexazinone (Velpar L) (site dependent rate) (2.5, 3.03, 3.48 lbs ai/ac) (2.8, 3.4, 3.9 kg ai/ha)	Understory	Total	Shannon diversity	4	2.60	2.80	-7.14
	Picloram (3.03 lbs ae/ac) (3.4 kg ae/ha)	Understory	Total	Shannon diversity	4	2.60	2.80	-7.14
	Triclopyr (Garlon) (3.92 lbs ae/ac) (4.4 kg ae/ha)	Understory	Total	Shannon diversity	4	2.80	2.80	0.00
	Dicamba + 2,4 D (4.01 lbs ae/ac of each) (4.5 kg ae/ha of each)	Understory	Total	Simpson diversity	4	0.89	0.91	-2.20
	Glyphosate (Roundup) (3.03 lbs ae/ac) (3.4 kg ae/ha)	Understory	Total	Simpson diversity	4	0.92	0.91	1.10
	Hexazinone (Pronone 10G) (site dependent rate) (2.5, 3.03, 3.48 lbs ai/ac) (2.8, 3.4, 3.9 kg ai/ha)	Understory	Total	Simpson diversity	4	0.89	0.91	-2.20
	Hexazinone (Velpar L) (site dependent rate) (2.5, 3.03, 3.48 lbs ai/ac) (2.8, 3.4, 3.9 kg ai/ha)	Understory	Total	Simpson diversity	4	0.88	0.91	-3.30
	Picloram (3.03 lbs ae/ac) (3.4 kg ae/ha)	Understory	Total	Simpson diversity	4	0.89	0.91	-2.20
	Triclopyr (Garlon) (3.92 lbs ae/ac) (4.4 kg ae/ha)	Understory	Total	Simpson diversity	4	0.90	0.91	-1.10
	Dicamba + 2,4 D (4.01 lbs ae/ac of each) (4.5 kg ae/ha of each)	Grass-Grasslike	Graminoids	Importance value	4	24.00	21.00	14.29
	Dicamba + 2,4 D (4.01 lbs ae/ac of each) (4.5 kg ae/ha of each)	All forbs	Herbaceous	Importance value	4	21.00	18.00	16.67
	Dicamba + 2,4 D (4.01 lbs ae/ac of each) (4.5 kg ae/ha of each)	Fern	Herbaceous	Importance value	4	0.20	0.70	-71.43
	Dicamba + 2,4 D (4.01 lbs ae/ac of each) (4.5 kg ae/ha of each)	Arborescent	Woody	Importance value	4	52.00	58.00	-10.34
	Dicamba + 2,4 D (4.01 lbs ae/ac of each) (4.5 kg ae/ha of each)	Nonarborescent	Woody	Importance value	4	24.00	30.00	-20.00

Study	*Herbicide*	*Group*	*Category*	*Response variable*	*N*	*Treatment*	*Control*	*% change*
	Dicamba + 2,4 D (4.01 lbs ae/ac of each) (4.5 kg ae/ha of each)	Semiwoody	Woody	Importance value	4	28.00	18.00	55.56
	Dicamba + 2,4 D (4.01 lbs ae/ac of each) (4.5 kg ae/ha of each)	Woody vine	Woody vine	Importance value	4	51.00	55.00	-7.27
	Glyphosate (Roundup) (3.03 lbs ae/ac) (3.4 kg ae/ha)	Grass-Grasslike	Graminoids	Importance value	4	25.00	21.00	19.05
	Glyphosate (Roundup) (3.03 lbs ae/ac) (3.4 kg ae/ha)	All forbs	Herbaceous	Importance value	4	28.00	18.00	55.56
	Glyphosate (Roundup) (3.03 lbs ae/ac) (3.4 kg ae/ha)	Fern	Herbaceous	Importance value	4	0.60	0.70	-14.29
	Glyphosate (Roundup) (3.03 lbs ae/ac) (3.4 kg ae/ha)	Arborescent	Woody	Importance value	4	55.00	58.00	-5.17
	Glyphosate (Roundup) (3.03 lbs ae/ac) (3.4 kg ae/ha)	Nonarborescent	Woody	Importance value	4	20.00	30.00	-33.33
	Glyphosate (Roundup) (3.03 lbs ae/ac) (3.4 kg ae/ha)	Semiwoody	Woody	Importance value	4	25.00	18.00	38.89
	Glyphosate (Roundup) (3.03 lbs ae/ac) (3.4 kg ae/ha)	Woody vine	Woody vine	Importance value	4	52.00	55.00	-5.45
	Hexazinone (Pronone 10G) (site dependent rate) (2.5, 3.03, 3.48 lbs ai/ac) (2.8, 3.4, 3.9 kg ai/ha)	Grass-Grasslike	Graminoids	Importance value	4	21.00	21.00	0.00
	Hexazinone (Pronone 10G) (site dependent rate) (2.5, 3.03, 3.48 lbs ai/ac) (2.8, 3.4, 3.9 kg ai/ha)	All forbs	Herbaceous	Importance value	4	27.00	18.00	50.00
	Hexazinone (Pronone 10G) (site dependent rate) (2.5, 3.03, 3.48 lbs ai/ac) (2.8, 3.4, 3.9 kg ai/ha)	Fern	Herbaceous	Importance value	4	0.80	0.70	14.29
	Hexazinone (Pronone 10G) (site dependent rate) (2.5, 3.03, 3.48 lbs ai/ac) (2.8, 3.4, 3.9 kg ai/ha)	Arborescent	Woody	Importance value	4	37.00	58.00	-36.21
	Hexazinone (Pronone 10G) (site dependent rate) (2.5, 3.03, 3.48 lbs ai/ac) (2.8, 3.4, 3.9 kg ai/ha)	Nonarborescent	Woody	Importance value	4	37.00	30.00	23.33

Study	*Herbicide*	*Group*	*Category*	*Response variable*	*N*	*Treatment*	*Control*	*% change*
	Hexazinone (Pronone 10G) (site dependent rate) (2.5, 3.03, 3.48 lbs ai/ac) (2.8, 3.4, 3.9 kg ai/ha)	Semiwoody	Woody	Importance value	4	17.00	18.00	-5.56
	Hexazinone (Pronone 10G) (site dependent rate) (2.5, 3.03, 3.48 lbs ai/ac) (2.8, 3.4, 3.9 kg ai/ha)	Woody vine	Woody vine	Importance value	4	58.00	55.00	5.45
	Hexazinone (Velpar L) (site dependent rate) (2.5, 3.03, 3.48 lbs ai/ac) (2.8, 3.4, 3.9 kg ai/ha)	Grass-Grasslike	Graminoids	Importance value	4	22.00	21.00	4.76
	Hexazinone (Velpar L) (site dependent rate) (2.5, 3.03, 3.48 lbs ai/ac) (2.8, 3.4, 3.9 kg ai/ha)	All forbs	Herbaceous	Importance value	4	20.00	18.00	11.11
	Hexazinone (Velpar L) (site dependent rate) (2.5, 3.03, 3.48 lbs ai/ac) (2.8, 3.4, 3.9 kg ai/ha)	Fern	Herbaceous	Importance value	4	2.30	0.70	228.57
	Hexazinone (Velpar L) (site dependent rate) (2.5, 3.03, 3.48 lbs ai/ac) (2.8, 3.4, 3.9 kg ai/ha)	Arborescent	Woody	Importance value	4	42.00	58.00	-27.59
	Hexazinone (Velpar L) (site dependent rate) (2.5, 3.03, 3.48 lbs ai/ac) (2.8, 3.4, 3.9 kg ai/ha)	Nonarborescent	Woody	Importance value	4	29.00	30.00	-3.33
	Hexazinone (Velpar L) (site dependent rate) (2.5, 3.03, 3.48 lbs ai/ac) (2.8, 3.4, 3.9 kg ai/ha)	Semiwoody	Woody	Importance value	4	15.00	18.00	-16.67
	Hexazinone (Velpar L) (site dependent rate) (2.5, 3.03, 3.48 lbs ai/ac) (2.8, 3.4, 3.9 kg ai/ha)	Woody vine	Woody vine	Importance value	4	77.00	55.00	40.00
	Picloram (3.03 lbs ae/ac) (3.4 kg ae/ha)	Grass-Grasslike	Graminoids	Importance value	4	21.00	21.00	0.00
	Picloram (3.03 lbs ae/ac) (3.4 kg ae/ha)	All forbs	Herbaceous	Importance value	4	30.00	18.00	66.67
	Picloram (3.03 lbs ae/ac) (3.4 kg ae/ha)	Fern	Herbaceous	Importance value	4	2.10	0.70	200.00
	Picloram (3.03 lbs ae/ac) (3.4 kg ae/ha)	Arborescent	Woody	Importance value	4	51.00	58.00	-12.07

Study	*Herbicide*	*Group*	*Category*	*Response variable*	*N*	*Treatment*	*Control*	*% change*
	Picloram (3.03 lbs ae/ac) (3.4 kg ae/ha)	Nonarborescent	Woody	Importance value	4	19.00	30.00	-36.67
	Picloram (3.03 lbs ae/ac) (3.4 kg ae/ha)	Semiwoody	Woody	Importance value	4	32.00	18.00	77.78
	Picloram (3.03 lbs ae/ac) (3.4 kg ae/ha)	Woody vine	Woody vine	Importance value	4	48.00	55.00	-12.73
	Triclopyr (Garlon) (3.92 lbs ae/ac) (4.4 kg ae/ha)	Grass-Grasslike	Graminoids	Importance value	4	33.00	21.00	57.14
	Triclopyr (Garlon) (3.92 lbs ae/ac) (4.4 kg ae/ha)	All forbs	Herbaceous	Importance value	4	37.00	18.00	105.56
	Triclopyr (Garlon) (3.92 lbs ae/ac) (4.4 kg ae/ha)	Fern	Herbaceous	Importance value	4	0.90	0.70	28.57
	Triclopyr (Garlon) (3.92 lbs ae/ac) (4.4 kg ae/ha)	Arborescent	Woody	Importance value	4	41.00	58.00	-29.31
	Triclopyr (Garlon) (3.92 lbs ae/ac) (4.4 kg ae/ha)	Nonarborescent	Woody	Importance value	4	21.00	30.00	-30.00
	Triclopyr (Garlon) (3.92 lbs ae/ac) (4.4 kg ae/ha)	Semiwoody	Woody	Importance value	4	18.00	18.00	0.00
	Triclopyr (Garlon) (3.92 lbs ae/ac) (4.4 kg ae/ha)	Woody vine	Woody vine	Importance value	4	49.00	55.00	-10.91
	Dicamba + 2,4 D (4.01 lbs ae/ac of each) (4.5 kg ae/ha of each)	Nonarborescent	Woody	Density (/ha)	4	1.00	2.00	-50.00
	Glyphosate (Roundup) (3.03 lbs ae/ac) (3.4 kg ae/ha)	Nonarborescent	Woody	Density (/ha)	4	1.00	2.00	-50.00
	Hexazinone (Pronone 10G) (site dependent rate) (2.5, 3.03, 3.48 lbs ai/ac) (2.8, 3.4, 3.9 kg ai/ha)	Nonarborescent	Woody	Density (/ha)	4	2.30	2.00	15.00
	Hexazinone (Velpar L) (site dependent rate) (2.5, 3.03, 3.48 lbs ai/ac) (2.8, 3.4, 3.9 kg ai/ha)	Nonarborescent	Woody	Density (/ha)	4	3.10	2.00	55.00
	Picloram (3.03 lbs ae/ac) (3.4 kg ae/ha)	Nonarborescent	Woody	Density (/ha)	4	0.70	2.00	-65.00

Study	*Herbicide*	*Group*	*Category*	*Response variable*	*N*	*Treatment*	*Control*	*% change*
	Triclopyr (Garlon) (3.92 lbs ae/ac) (4.4 kg ae/ha)	Nonarborescent	Woody	Density (/ha)	4	0.90	2.00	-55.00
Miller et al. 1995	Triclopyr and glyphosate (for 5 years) (rates not provided)	Grasses/grasslike (yr 1)	Graminoids	Cover	53	35.00	40.00	-12.50
	Triclopyr and glyphosate (for 5 years) (rates not provided)	Grasses/grasslike (yr 8)	Graminoids	Cover	53	42.00	36.00	16.67
	Triclopyr and glyphosate (for 5 years) (rates not provided)	Forbs (yr 1)	Herbaceous	Cover	53	30.00	27.00	11.11
	Triclopyr and glyphosate (for 5 years) (rates not provided)	Forbs (yr 8)	Herbaceous	Cover	53	7.00	6.00	16.67
	Triclopyr and glyphosate (for 5 years) (rates not provided)	Herbaceous (yr 1)	Herbaceous	Cover	53	80.00	84.00	-4.76
	Triclopyr and glyphosate (for 5 years) (rates not provided)	Total (yr 8)	Total	Cover	53	152.00	160.00	-5.00
	Triclopyr and glyphosate (for 5 years) (rates not provided)	Semiwoody (yr 1)	Woody	Cover	53	5.00	6.00	-16.67
	Triclopyr and glyphosate (for 5 years) (rates not provided)	Semiwoody (yr 8)	Woody	Cover	53	25.00	6.00	316.67
	Triclopyr and glyphosate (for 5 years) (rates not provided)	Vines (yr 1)	Woody vines	Cover	53	6.00	7.00	-14.29
	Triclopyr and glyphosate (for 5 years) (rates not provided)	Vines (yr 8)	Woody vines	Cover	53	20.00	12.00	66.67
Zutter & Miller 1998	Sulfometuron (repeated annually for 11 years) (4-6 oz/ac) (0.58-0.88 L/ha) + glyphosate (repeated annually for 3 years) (2%)	Herbaceous	Herbaceous	Cover	5	2.00	15.00	-86.67
	Sulfometuron (repeated annually for 11 years) (4-6 oz/ac) (0.58-0.88 L/ha) + glyphosate (repeated annually for 3 years) (2%)	Arborescent	Woody	Cover	5	24.00	20.00	20.00
	Sulfometuron (repeated annually for 11 years) (4-6 oz/ac) (0.58-0.88 L/ha) + glyphosate (repeated annually for 3 years) (2%)	Nonarborescent	Woody	Cover	5	44.00	77.00	-42.86

Study	*Herbicide*	*Group*	*Category*	*Response variable*	*N*	*Treatment*	*Control*	*% change*
	Sulfometuron (repeated annually for 11 years) (4-6 oz/ac) (0.58-0.88 L/ha) + glyphosate (repeated annually for 3 years) (2%)	Total woody	Woody	Cover	5	60.00	83.00	-27.71
	Triclopyr (5%) + triclopyr (5%) + sulfometuron (repeated annually for 11 years) (4-6 oz/ac) (0.58-0.88 L/ha) + glyphosate (repeated annually for 3 years) (2%)	Arborescent	Woody	Cover	5	1.00	20.00	-95.00
	Triclopyr (5%) + triclopyr (5%) + sulfometuron (repeated annually for 11 years) (4-6 oz/ac) (0.58-0.88 L/ha) + glyphosate (repeated annually for 3 years) (2%)	Nonarborescent	Woody	Cover	5	5.00	77.00	-93.51
	Triclopyr (5%) + triclopyr (5%) + sulfometuron (repeated annually for 11 years) (4-6 oz/ac) (0.58-0.88 L/ha) + glyphosate (repeated annually for 3 years) (2%)	Herbaceous	Herbaceous	Cover	5	2.00	15.00	-86.67
	Triclopyr (5%) + triclopyr (5%) + sulfometuron (repeated annually for 11 years) (4-6 oz/ac) (0.58-0.88 L/ha) + glyphosate (repeated annually for 3 years) (2%)	Total woody	Woody	Cover	5	6.00	83.00	-92.77
	Triclopyr (5%) + triclopyr (5%)	Herbaceous	Herbaceous	Cover	5	6.00	15.00	-60.00
	Triclopyr (5%) + triclopyr (5%)	Arborescent	Woody	Cover	5	4.00	20.00	-80.00
	Triclopyr (5%) + triclopyr (5%)	Nonarborescent	Woody	Cover	5	31.00	77.00	-59.74
	Triclopyr (5%) + triclopyr (5%)	Total woody	Woody	Cover	5	34.00	83.00	-59.04
Zutter et al. 1987	Glyphosate (2%) + sulfometuron (0.37 lbs ai/ac) (0.42 kg ai/ha) + sulfometuron (0.23 lbs ai/ac) (0.26 kg ai/ha) + glyphosate (repeated as needed) (2%)	Importance value (yr 2)	Total	Shannon diversity	4	1.09	1.76	-38.07

Study	*Herbicide*	*Group*	*Category*	*Response variable*	*N*	*Treatment*	*Control*	*% change*
	Glyphosate (2%) + sulfometuron (0.37 lbs ai/ac) (0.42 kg ai/ha) + sulfometuron (0.23 lbs ai/ac) (0.26 kg ai/ha) + glyphosate (repeated as needed) (2%)	Importance value (yr 3)	Total	Shannon diversity	4	1.77	2.14	-17.29
	Glyphosate (2%) + sulfometuron (0.37 lbs ai/ac) (0.42 kg ai/ha) + sulfometuron (0.23 lbs ai/ac) (0.26 kg ai/ha) + glyphosate (repeated as needed) (2%)	Relative cover (yr 2)	Total	Shannon diversity	4	0.96	1.56	-38.46
	Glyphosate (2%) + sulfometuron (0.37 lbs ai/ac) (0.42 kg ai/ha) + sulfometuron (0.23 lbs ai/ac) (0.26 kg ai/ha) + glyphosate (repeated as needed) (2%)	Relative cover (yr 3)	Total	Shannon diversity	4	1.31	1.77	-25.99
	Glyphosate (2%) + sulfometuron (0.37 lbs ai/ac) (0.42 kg ai/ha) + sulfometuron (0.23 lbs ai/ac) (0.26 kg ai/ha) + glyphosate (repeated as needed) (2%)	Relative frequency (yr 2)	Total	Shannon diversity	4	1.16	1.88	-38.30
	Glyphosate (2%) + sulfometuron (0.37 lbs ai/ac) (0.42 kg ai/ha) + sulfometuron (0.23 lbs ai/ac) (0.26 kg ai/ha) + glyphosate (repeated as needed) (2%)	Relative frequency (yr 3)	Total	Shannon diversity	4	2.01	2.34	-14.10
	Triclopyr ester (undiluted) + sulfometuron (0.37 lbs ai/ac) (0.42 kg ai/ha)	Importance value (yr 2)	Total	Shannon diversity	4	1.56	1.76	-11.36
	Triclopyr ester (undiluted) + sulfometuron (0.37 lbs ai/ac) (0.42 kg ai/ha)	Importance value (yr 3)	Total	Shannon diversity	4	2.10	2.14	-1.87
	Triclopyr ester (undiluted) + sulfometuron (0.37 lbs ai/ac) (0.42 kg ai/ha)	Relative cover (yr 2)	Total	Shannon diversity	4	1.24	1.56	-20.51

Study	*Herbicide*	*Group*	*Category*	*Response variable*	*N*	*Treatment*	*Control*	*% change*
	Triclopyr ester (undiluted) + sulfometuron (0.37 lbs ai/ac) (0.42 kg ai/ha)	Relative cover (yr 3)	Total	Shannon diversity	4	1.58	1.77	-10.73
	Triclopyr ester (undiluted) + sulfometuron (0.37 lbs ai/ac) (0.42 kg ai/ha)	Relative frequency (yr 2)	Total	Shannon diversity	4	1.76	1.88	-6.38
	Triclopyr ester (undiluted) + sulfometuron (0.37 lbs ai/ac) (0.42 kg ai/ha)	Relative frequency (yr 3)	Total	Shannon diversity	4	2.35	2.34	0.43
	Glyphosate (2%) + sulfometuron (0.37 lbs ai/ac) (0.42 kg ai/ha) + sulfometuron (0.23 lbs ai/ac) (0.26 kg ai/ha) + glyphosate (repeated as needed) (2%)	Importance value (yr 2)	Total	Simpson diversity	4	0.42	0.22	90.91
	Glyphosate (2%) + sulfometuron (0.37 lbs ai/ac) (0.42 kg ai/ha) + sulfometuron (0.23 lbs ai/ac) (0.26 kg ai/ha) + glyphosate (repeated as needed) (2%)	Importance value (yr 3)	Total	Simpson diversity	4	0.24	0.16	50.00
	Glyphosate (2%) + sulfometuron (0.37 lbs ai/ac) (0.42 kg ai/ha) + sulfometuron (0.23 lbs ai/ac) (0.26 kg ai/ha) + glyphosate (repeated as needed) (2%)	Relative cover (yr 2)	Total	Simpson diversity	4	0.48	0.28	71.43
	Glyphosate (2%) + sulfometuron (0.37 lbs ai/ac) (0.42 kg ai/ha) + sulfometuron (0.23 lbs ai/ac) (0.26 kg ai/ha) + glyphosate (repeated as needed) (2%)	Relative cover (yr 3)	Total	Simpson diversity	4	0.42	0.24	75.00
	Glyphosate (2%) + sulfometuron (0.37 lbs ai/ac) (0.42 kg ai/ha) + sulfometuron (0.23 lbs ai/ac) (0.26 kg ai/ha) + glyphosate (repeated as needed) (2%)	Relative frequency (yr 2)	Total	Simpson diversity	4	0.39	0.18	116.67

Study	*Herbicide*	*Group*	*Category*	*Response variable*	*N*	*Treatment*	*Control*	*% change*
	Glyphosate (2%) + sulfometuron (0.37 lbs ai/ac) (0.42 kg ai/ha) + sulfometuron (0.23 lbs ai/ac) (0.26 kg ai/ha) + glyphosate (repeated as needed) (2%)	Relative frequency (yr 3)	Total	Simpson diversity	4	0.16	0.11	45.45
	Triclopyr ester (undiluted) + sulfometuron (0.37 lbs ai/ac) (0.42 kg ai/ha)	Importance value (yr 2)	Total	Simpson diversity	4	0.29	0.22	31.82
	Triclopyr ester (undiluted) + sulfometuron (0.37 lbs ai/ac) (0.42 kg ai/ha)	Importance value (yr 3)	Total	Simpson diversity	4	0.18	0.16	12.50
	Triclopyr ester (undiluted) + sulfometuron (0.37 lbs ai/ac) (0.42 kg ai/ha)	Relative cover (yr 2)	Total	Simpson diversity	4	0.44	0.28	57.14
	Triclopyr ester (undiluted) + sulfometuron (0.37 lbs ai/ac) (0.42 kg ai/ha)	Relative cover (yr 3)	Total	Simpson diversity	4	0.32	0.24	33.33
	Triclopyr ester (undiluted) + sulfometuron (0.37 lbs ai/ac) (0.42 kg ai/ha)	Relative frequency (yr 2)	Total	Simpson diversity	4	0.21	0.18	16.67
	Triclopyr ester (undiluted) + sulfometuron (0.37 lbs ai/ac) (0.42 kg ai/ha)	Relative frequency (yr 3)	Total	Simpson diversity	4	0.11	0.11	0.00
	Glyphosate (2%) + sulfometuron (0.37 lbs ai/ac) (0.42 kg ai/ha) + sulfometuron (0.23 lbs ai/ac) (0.26 kg ai/ha) + glyphosate (repeated as needed) (2%)	Herbaceous (yr 1)	Herbaceous	Cover	4	2.00	74.00	-97.30
	Glyphosate (2%) + sulfometuron (0.37 lbs ai/ac) (0.42 kg ai/ha) + sulfometuron (0.23 lbs ai/ac) (0.26 kg ai/ha) + glyphosate (repeated as needed) (2%)	Herbaceous (yr 3)	Herbaceous	Cover	4	23.00	80.00	-71.25
	Triclopyr ester (undiluted) + sulfometuron (0.37 lbs ai/ac) (0.42 kg ai/ha)	Herbaceous (yr 1)	Herbaceous	Cover	4	27.00	74.00	-63.51

Study	Herbicide	Group	Category	Response variable	N	Treatment	Control	% change
	Triclopyr ester (undiluted) + sulfometuron (0.37 lbs ai/ac) (0.42 kg ai/ha)	Herbaceous (yr 3)	Herbaceous	Cover	4	80.00	80.00	0.00
	Glyphosate (2%) + sulfometuron (0.37 lbs ai/ac) (0.42 kg ai/ha) + sulfometuron (0.23 lbs ai/ac) (0.26 kg ai/ha) + glyphosate (repeated as needed) (2%)	Herbaceous (yr 1)	Herbaceous	Biomass	4	0.00	2.60	-100.00
	Glyphosate (2%) + sulfometuron (0.37 lbs ai/ac) (0.42 kg ai/ha) + sulfometuron (0.23 lbs ai/ac) (0.26 kg ai/ha) + glyphosate (repeated as needed) (2%)	Herbaceous (yr 3)	Herbaceous	Biomass	4	0.30	3.20	-90.63
	Triclopyr ester (undiluted) + sulfometuron (0.37 lbs ai/ac) (0.42 kg ai/ha)	Herbaceous (yr 1)	Herbaceous	Biomass	4	1.20	2.60	-53.85
	Triclopyr ester (undiluted) + sulfometuron (0.37 lbs ai/ac) (0.42 kg ai/ha)	Herbaceous (yr 3)	Herbaceous	Biomass	4	2.60	3.20	-18.75
Zutter et al. 1986	Sulfometuron (0.37 lbs ai/ac in 9.94 gal/ac) (0.42 kg ai/ha in 93 L/ha) + sulfometuron (0.22 lbs ai/ac in 13.04 gal/ac) (0.25 kg ai/ha in 122 L/ha) + glyphosate (2%) + glyphosate (repeated as needed) (2%)	Herbaceous (yr 1)	Herbaceous	Cover	4	2.40	73.50	-96.73
	Sulfometuron (0.37 lbs ai/ac in 9.94 gal/ac) (0.42 kg ai/ha in 93 L/ha) + sulfometuron (0.22 lbs ai/ac in 13.04 gal/ac) (0.25 kg ai/ha in 122 L/ha) + glyphosate (2%) + glyphosate (repeated as needed) (2%)	Herbaceous (yr 2)	Herbaceous	Cover	4	1.40	82.50	-98.30

Study	*Herbicide*	*Group*	*Category*	*Response variable*	*N*	*Treatment*	*Control*	*% change*
	Sulfometuron (0.37 lbs ai/ac in 9.94 gal/ac) (0.42 kg ai/ha in 93 L/ha) + sulfometuron (0.22 lbs ai/ac in 13.04 gal/ac) (0.25 kg ai/ha in 122 L/ha) + glyphosate (2%) + glyphosate (repeated as needed) (2%)	Woody (yr 2)	Woody	Cover	4	0.20	0.60	-66.67
	Triclopyr ester (undiluted) + sulfometuron (0.37 lbs ai/ac in 9.94 gal/ac) (0.42 kg ai/ha in 93 L/ha)	Herbaceous (yr 1)	Herbaceous	Cover	4	28.10	73.50	-61.77
	Triclopyr ester (undiluted) + sulfometuron (0.37 lbs ai/ac in 9.94 gal/ac) (0.42 kg ai/ha in 93 L/ha)	Herbaceous (yr 2)	Herbaceous	Cover	4	78.80	82.50	-4.48
	Triclopyr ester (undiluted) + sulfometuron (0.37 lbs ai/ac in 9.94 gal/ac) (0.42 kg ai/ha in 93 L/ha)	Woody (yr 2)	Woody	Cover	4	0.50	0.60	-16.67
	Sulfometuron (0.37 lbs ai/ac in 9.94 gal/ac) (0.42 kg ai/ha in 93 L/ha) + sulfometuron (0.22 lbs ai/ac in 13.04 gal/ac) (0.25 kg ai/ha in 122 L/ha) + glyphosate (2%) + glyphosate (repeated as needed) (2%)	Herbaceous (yr 1)	Herbaceous	Biomass	4	29.70	2695.30	-98.90
	Sulfometuron (0.37 lbs ai/ac in 9.94 gal/ac) (0.42 kg ai/ha in 93 L/ha) + sulfometuron (0.22 lbs ai/ac in 13.04 gal/ac) (0.25 kg ai/ha in 122 L/ha) + glyphosate (2%) + glyphosate (repeated as needed) (2%)	Herbaceous (yr 2)	Herbaceous	Biomass	4	14.90	2398.80	-99.38
	Sulfometuron (0.37 lbs ai/ac in 9.94 gal/ac) (0.42 kg ai/ha in 93 L/ha) + sulfometuron (0.22 lbs ai/ac in 13.04 gal/ac) (0.25 kg ai/ha in 122 L/ha) + glyphosate (2%) + glyphosate (repeated as needed) (2%)	Woody (yr 1)	Woody	Biomass	4	5.40	6.10	-11.48

Study	*Herbicide*	*Group*	*Category*	*Response variable*	*N*	*Treatment*	*Control*	*% change*
	Sulfometuron (0.37 lbs ai/ac in 9.94 gal/ac) (0.42 kg ai/ha in 93 L/ha) + sulfometuron (0.22 lbs ai/ac in 13.04 gal/ac) (0.25 kg ai/ha in 122 L/ha) + glyphosate (2%) + glyphosate (repeated as needed) (2%)	Woody (yr 2)	Woody	Biomass	4	2.80	16.50	-83.03
	Triclopyr ester (undiluted) + sulfometuron (0.37 lbs ai/ac in 9.94 gal/ac) (0.42 kg ai/ha in 93 L/ha)	Herbaceous (yr 1)	Herbaceous	Biomass	4	1146.20	2695.30	-57.47
	Triclopyr ester (undiluted) + sulfometuron (0.37 lbs ai/ac in 9.94 gal/ac) (0.42 kg ai/ha in 93 L/ha)	Woody (yr 1)	Woody	Biomass	4	4.70	6.10	-22.95
	Triclopyr ester (undiluted) + sulfometuron (0.37 lbs ai/ac in 9.94 gal/ac) (0.42 kg ai/ha in 93 L/ha)	Woody (yr 2)	Woody	Biomass	4	16.10	16.50	-2.42
	Triclopyr ester (undiluted) + sulfometuron (0.37 lbs ai/ac in 9.94 gal/ac) (0.42 kg ai/ha in 93 L/ha)	Herbaceous (yr 2)	Herbaceous	Biomass	4	2436.40	2398.80	1.57

Species: Common name	Species: Scientific name	Historic range	Vertebrate population where endangered or threatened	Status	When listed	Critical habitat	Special rules
Reptiles							
*	*	*	*	*	*	*	
Lizard, Maria Island ground	Cnemidophorus vanzoi	West Indies: St. Lucia (Maria Islands).	Entire	E	443	NA	NA
*	*	*	*	*	*	*	
Snake, Maria Island	Liophis ornatus	West Indies: St. Lucia (Maria Islands).	Entire	E	443	NA	NA
*	*	*	*	*	*	*	
Turtle, Brazilian (=Hoge's) sideneck.	Phrynops hogei	Brazil	Entire	E	443	NA	NA
*	*	*	*	*	*	*	
Turtle, Cat Island	Trachemys terrapen	West Indies: Jamaica, Bahamas.	Cat Island in the Bahamas.	E	443	NA	NA
*	*	*	*	*	*	*	
Turtle, Inagua Island	Trachemys stejnegeri malonei.	West Indies: Bahamas (Great Inagua Island).	Entire	E	443	NA	NA
*	*	*	*	*	*	*	
Turtle, South American red-lined.	Trachemys scripta callirostris.	Colombia, Venezuela	Entire	E	443	NA	NA
*	*	*	*	*	*	*	

Dated: September 24, 1991.

Sam Marler,

Acting Director.

[FR Doc. 91-23461 Filed 9-27-91; 8:45 am]

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DEPARTMENT OF COMMERCE

National Oceanic and Atmospheric Administration

DEPARTMENT OF THE INTERIOR

Fish and Wildlife Service

50 CFR Part 17

RIN 1018-AB36

Endangered and Threatened Wildlife and Plants; Threatened Status for the Gulf Sturgeon

AGENCIES: Fish and Wildlife Service, Interior, and National Oceanic and Atmospheric Administration (NOAA), Commerce.

ACTION: Final rule.

SUMMARY: The Service determines the Gulf sturgeon (*Acipenser oxyrhynchus desotoi*) to be a threatened species, pursuant to the Endangered Species Act of 1973 (Act), as amended. This rule has been coordinated with NOAA and they have cosigned the document. This large fish ranges from Lake Pontchartrain in Louisiana to Tampa Bay in Florida. Gulf sturgeon stocks have been greatly reduced or extirpated throughout much of the historic range by overfishing, dam construction and habitat degradation. This action will implement the protection and recovery provisions afforded by the Act for the Gulf sturgeon.

EFFECTIVE DATE: October 30, 1991.

ADDRESSES: The complete files for this rule are available for inspection, by appointment, during normal business hours at the Jacksonville Field Office, U.S. Fish and Wildlife Service, 3100 University Boulevard South, suite 120, Jacksonville, Florida 32216.

FOR FURTHER INFORMATION CONTACT: David J. Wesley, Field Supervisor, at the above address (telephone 904/791-2580 or FTS 946-2580).

SUPPLEMENTARY INFORMATION:

Background

The Gulf sturgeon (*Acipenser oxyrhynchus desotoi*), also known as the Gulf of Mexico sturgeon, is a subspecies of the Atlantic sturgeon (*Acipenser oxyrhynchus*). The Gulf sturgeon was described by Vladykov in 1955. It is a large, nearly cylindrical fish with an extended snout, vertical mouth, chin barbels, and with the upper lobe of the tail longer than the lower. Adults range from 1.8–2.4 meters (6–8 feet) or more in length, with adult females larger than males. The skin is scaleless, brown dorsally and pale ventrally, and imbedded with five rows of bony plates. The Gulf sturgeon has a longer head, pectoral fins, and spleen than the related Atlantic sturgeon (Huff 1975, Wooley 1985).

The following information is derived primarily from Barkuloo (1988). Historically, the Gulf sturgeon occurred from the Mississippi River to Tampa Bay, Florida. It still occurs, at least occasionally, throughout this range, but in greatly reduced numbers. The fish is essentially confined to the eastern Gulf of Mexico, possibly because this portion of the Gulf has predominately hard bottoms that are better suited to the Gulf sturgeon's feeding habits. (The western Gulf has mostly mud, clay, and silt bottom sediments.) Adult fish are bottom feeders, eating primarily invertebrates, including brachiopods, insect larvae, mollusks, worms, and crustaceans. Gulf sturgeon are anadromous, with reproduction occurring in fresh water but with most adult feeding taking place in the Gulf of Mexico and its estuaries. The fish probably return to breed in the same river system in which they hatched. Adult sturgeon enter the Apalachicola and Suwannee River Systems from February through April. Spawning is believed to occur in areas of deep water and clean (rock, gravel, or sand) bottoms. The eggs are sticky and adhere in clumps or strings to snags, outcroppings, or other clean surfaces. Larvae have been collected in April and May in the Apalachicola River. Adults remain in fresh water as late as November. The adults lose weight while in fresh water but regain it while wintering in estuaries or the Gulf of Mexico. In the Suwannee River, Florida, female sturgeon require 8 to 12 years, and males 7 to 10 years, to reach sexual maturity (Huff 1975). The Gulf sturgeon, therefore, is a slow-maturing, long-lived fish.

The Gulf sturgeon has historically been of commercial importance, with the eggs used for caviar, the flesh for smoked fish, and the swim bladder yielding isinglass, a gelatin used in food products and glues. Available landing

records for Gulf sturgeon indicate that the principal historic fisheries were in Florida and Alabama, with little directed fishing in the other Gulf States; mainly by-catch from other fishing. In Florida, recorded catches peaked about the turn of the century, and while fluctuating over the years, have decreased drastically since that time. The decline was initially due to overfishing, but subsequent dam construction has impacted habitat and eliminated or seriously reduced some populations in more recent years.

Service involvement with the Gulf sturgeon began with monitoring and other studies of the Apalachicola River population by the Service's Panama City, Florida, Fisheries Assistance Office in 1979. The fish was included as a category 2 species in the Service's December 30, 1982 (47 FR 58454), and September 18, 1985 (50 FR 37958), vertebrate review notices, and in the January 6, 1989 (54 FR 554), animal notice of review. These notices indicated that the Gulf sturgeon was a species for which listing as threatened or endangered was possibly appropriate. In 1980, the Service's Jacksonville, Florida, Area Office contracted a status survey report on the Gulf sturgeon (Hollowell 1980). The report concluded that the fish had been reduced to a small population due to overfishing and habitat loss, and that any further adverse changes would make its survival questionable. In 1988, the Panama City, Florida, Office completed a report (Barkuloo 1988) on the conservation status of the Gulf sturgeon, recommending that the subspecies be listed as a threatened species pursuant to the Act. The Service proposed the Gulf sturgeon for listing as a threatened species on May 2, 1990 (55 FR 18357).

Subsequent to publication of the proposed rule, Service contacts with agencies and individuals working on conservation of the Gulf sturgeon indicated that it would be in the best interest of the species to increase post listing regulatory flexibility relative to Service permitting requirements. The Endangered Species Act allows such flexibility in the case of species that are classified as threatened. Accordingly, a special rule has been added to allow taking of the Gulf sturgeon for certain purposes without a Federal permit, provided that the taking is done in accordance with applicable State fish and wildlife conservation laws and regulations.

The Service and the National Marine Fisheries Service (NMFS) executed a Memorandum of Understanding (MOU) in 1974 regarding jurisdictional responsibilities and listing procedures under the Endangered Species Act. Based upon the terms of the MOU, the Service has determined, for purposes of this final rule, that it has jurisdictional authority to list this species because the Gulf sturgeon spends the majority of its lifespan in fresh water. However, the NMFS also claims jurisdiction, contending that the Presidential Reorganization Plan No. 4 of 1970 clearly placed anadromous fish under NMFS jurisdiction, and, thus the intended scope of the MOU did not include anadromous fish.

Although the agencies intend to resolve this disagreement in the future, both agree that it is in the best interest of the Gulf sturgeon to list the subspecies without further delay. Until the jurisdictional issue is resolved, the Service will be responsible for the Gulf sturgeon once the listing becomes effective. Both agencies have signed this rule to eliminate confusion while the issue of jurisdiction is under review.

Summary of Comments and Recommendations

In the May 2, 1990, proposed rule and associated notifications, all interested parties were requested to submit factual reports or information that might contribute to the development of a final rule. Appropriate State agencies, Federal agencies, scientific organizations, and other interested parties were contacted and requested to comment. Newspaper notices were published in the Mobile, Alabama, "Press Register" on May 19, 1990; in the Atlanta, Georgia, "Constitution" on May 20, 1990; in the Tallahassee, Florida, "Democrat" on May 22, 1990; in the New Orleans, Louisiana, "Times-Picayune" on May 22, 1990; and in the Jackson, Mississippi, "Clarion-Ledger" on June 4, 1990.

Nine comments were received during the comment period. The proposal was supported by the Alabama Department of Conservation and Natural Resources; the Mississippi Department of Wildlife, Fisheries, and Parks; Florida's Marine Fisheries Commission, Department of Natural Resources, and Game and Fresh Water Fish Commission; and a representative of a private conservation foundation.

Mississippi commented that the proposed rule was misleading in stating that the Gulf sturgeon was essentially confined to the eastern Gulf and in implying that the only viable populations remained in Florida. They pointed out that a potentially healthy population still exists in the Pearl River, and that spawning areas were still available in the lower 150 miles of the Pearl River, including some tributaries. They further stated that a sturgeon fishery existed on the Pascagoula River in the early twentieth century, and that additional survey work should be done in Mississippi rivers. Service response: The eastern Gulf of Mexico distribution referred to in the proposed rule meant that the Gulf sturgeon was essentially restricted to rivers east of the Mississippi, not that the species was restricted to Florida. Historical catch data, however, do indicate that Florida supported the largest part of the distribution. This final rule has incorporated the additional information provided by Mississippi. The Service agrees that further survey work will be necessary to determine the status of the Gulf sturgeon in several of the Gulf coast rivers, but believes that sufficient evidence exists to indicate that the subspecies is threatened over most, if not all, of its range.

The Louisiana Department of Wildlife and Fisheries stated that the Gulf sturgeon was formerly found in the Pearl River and the major Lake Pontchartrain tributaries, but that the current status was unknown. They reported that the Louisiana Wildlife and Fisheries Commission had closed all Louisiana waters to taking of sturgeon effective May 20, 1990.

A private individual expressed concern about potential economic effects of the listing, particularly with regard to interfering with commercial fishing. Service response: Section 4(b) of the Act requires that listing decisions be made solely on the basis of the best available scientific and commercial data; economic factors may not be considered. Nonetheless, the Service does not anticipate that the listing of the Gulf sturgeon will impede commercial fishing. Take of the fish is already prohibited by Louisiana, Mississippi, Alabama, and Florida. Existing Federal (National Marine Fisheries Service) regulations currently require the use of turtle excluder devices (TEDs) by shrimpers, and potential future requirements to reduce the incidental finfish catch should also reduce the incidental take of Gulf sturgeon.

The Lower Mississippi Division of the U.S. Army Corps of Engineers indicated a number of civil works projects that would require coordination with the Fish and Wildlife Service. Service response: The Fish and Wildlife Service has already conferred with, and will now consult with Federal agencies pursuant to activities that may affect the Gulf sturgeon, as required by section 7 of the Act.

Summary of Factors Affecting the Species

After a thorough review and consideration of all information available, the Service has determined that the Gulf sturgeon should be classified as a threatened species. Procedures found at Section 4(a)(1) of the Endangered Species Act (16 U.S.C. 1531 *et seq.* and regulations (50 CFR part 424) promulgated to implement the listing provisions of the Act were followed. A species may be determined to be an endangered or threatened species due to one or more of the five factors described in section 4(a)(1). These factors and their application to the Gulf sturgeon (*Acipenser oxyrhynchus desotoi*) are as follows:

A. The Present or Threatened Destruction, Modification, or Curtailment of its Habitat or Range

The Gulf sturgeon formerly ranged from the Mississippi River eastward to the Tampa Bay area on the west coast of Florida. Three major rivers (the Pearl in Mississippi, the Alabama in Alabama, and the Apalachicola in Florida) within the range of the Gulf sturgeon have been dammed, preventing use of upstream areas for spawning. The Gulf sturgeon is apparently unable to pass through dam systems. The Ross Barnett Dam near Jackson, Mississippi, prevents sturgeon movement further upstream, although sturgeon still have access to the lower 240 kilometers (150 miles) of the Pearl, and the tributaries in that area. Substantial spawning habitat remains in the Pearl and large tributaries like the Bogue Chitto and Strong Rivers (Mississippi Department of Wildlife, Fisheries, and Parks, *in litt.* 1990). Wooley and Crateau (1985) estimated that construction of the Jim Woodruff Lock and Dam on the Apalachicola River in the 1950's restricted Gulf sturgeon to 172 kilometers (107 miles) of the 1,018 kilometers (636 miles) of river habitat formerly available in the Apalachicola-Chattahoochee-Flint River System. Prior to dam construction, the Gulf sturgeon used all three rivers; subsequently the fish has been restricted to that portion of the Apalachicola River below the dam. Even if the Jim Woodruff Dam could be passed by Gulf sturgeon, the tributaries of the Apalachicola have many additional dams; 14 on the Chattahoochee and three on the Flint. A breeding population of Gulf sturgeon in Bear Creek, Bay County, Florida, was apparently extirpated due to construction of a dam in 1962.

In addition to the structures preventing Gulf sturgeon from reaching spawning areas, dredging, desnagging, and spoil deposition carried out in connection with channel improvement and maintenance represent a threat to the Gulf sturgeon. Although precise spawning areas are not known, indications are that deep holes and rock surfaces are important for spawning. Modification of such features, especially in rivers in which upstream migration is already limited by dams, could further jeopardize the already reduced stocks of the Gulf sturgeon.

The majority of the range of the Gulf sturgeon is along the panhandle and northwest peninsular coasts of Florida. Tampa Bay, Florida, was the site of the first significant fishery for the Gulf sturgeon. Fifteen hundred fish were taken when the fishery began in 1886–1887, 2,000 in 1887–1888, and only seven fish in 1888–1889, at which time the fishery ended. Only occasional Gulf sturgeon have been taken there since that time. These are believed to originate in other river systems; the Tampa Bay breeding population is considered extirpated.

The Apalachicola River population of the Gulf sturgeon supported a major fishery at the beginning of the century, but population estimates from 1983–1988 by the Service's Panama City, Florida, Fisheries Assistance Office range from 60–285 fish. Any additional decline in this population could result in its extirpation. The Ochlockonee River supported a fishery until the 1950's, but no Gulf sturgeon have been reported there in recent years.

The Suwannee River is believed to support the healthiest remaining population of the Gulf sturgeon, and the population currently appears stable. Steve Carr (in Barkuloo 1988) of the Caribbean Conservation Foundation caught and released 300 Gulf sturgeon during a tagging program in 1988, and 500 in 1989. However, the population may have been reduced seriously following a large commercial harvest in 1983–1984. the Suwannee River currently has good water quality but future development in its watershed has the potential to lower water quality there.

Gulf sturgeon populations in other states are believed to remain low following overfishing and habitat change earlier in the century. Based on the limited data available, the Gulf sturgeon is rare in these states. Incidental catches of Gulf sturgeon are unusual enough in some areas to attract newspaper accounts.

Alabama formerly supported a Gulf sturgeon fishery; commercial landing records from 1927 to 1964 show a decline from a range of 2,850–15,134 pounds taken during the first five years of the fishery (1927–1931) to 100–3,500 pounds in the last five years (1960–1964). Gulf sturgeon have been taken in the Mobile River System as recently as 1986 and 1987, but captures in coastal waters have not been reported since 1980.

In Mississippi, Miranda and Jackson (1987) collected a Gulf sturgeon from the Pascagoula River in June 1987 during 30 net-nights of effort. They reported the capture of another Gulf sturgeon on the Chickasawhay, a tributary of the Pascagoula, in 1985.

In 1988 the Louisiana Department of Wildlife and Fisheries began collecting information on Gulf sturgeon. As of March 1989, specimens had been recorded from Lake Pontchartrain (a total of six adults and subadults), Halfmoon Island (one juvenile), and the Pearl River (one adult and five juveniles). Dr. Frank Petzold of Mississippi State University caught 63 juvenile to subadult Gulf sturgeon in the Pearl River in 1985. While Miranda and Jackson took no Gulf sturgeon in that river during 46 net-nights in June 1987, Dwight Bradshaw (pers. comm.) of Mississippi State University believes that significant numbers of Gulf sturgeon remain in the Pearl.

B. Overutilization for Commercial, Recreational, Scientific, or Educational Purposes

Although there currently is no directed fishery for Gulf sturgeon, incidental take by commercial shrimpers and gill net fishermen may be significant (Wooley and Crateau 1985). Use of turtle excluder devices on shrimp trawls may help reduce incidental catch.

C. Disease or Predation

Not known to be a factor.

D. The Inadequacy of Existing Regulatory Mechanisms

The Gulf sturgeon is listed as a species of special concern by the Florida Game and Fresh Water Fish Commission (Title 39–27.05, Florida Administrative Code) and as an endangered species by the Mississippi Department of Wildlife, Fisheries, and Parks. Take is prohibited in both states. Take of Gulf sturgeon in Alabama is prohibited (Chapter 220–2–26 of Regulations of Department of Conservation and Natural Resources). On May 20, 1990, the Louisiana Wildlife and Fisheries Commission prohibited the take of all species of sturgeon in Louisiana waters. There is currently no known directed fishery for the Gulf sturgeon anywhere in its range.

E. Other Natural or Manmade Factors Affecting Its Continued Existence

Since the Gulf sturgeon is slow to mature, it is unable to rapidly establish a breeding population. The fish probably return to their natal river to breed; if so, recolonization of extirpated populations from other river systems is likely to be slow.

There is a potential threat to the Gulf sturgeon from hybridization with the white sturgeon (*Acipenser transmontanus*), a fish native to the Pacific coast of North America (Dr. James D. Williams, National Fisheries Research Center, Gainesville, Florida; pers. comm.). There have been preliminary attempts to introduce white sturgeon for aquaculture within the range of the Gulf sturgeon. Since species of *Acipenser* are capable of hybridization, any releases of white sturgeon within the range of the Gulf sturgeon could threaten the survival of the latter species.

Poor water quality may also be a threat. All major rivers in the fish's historic range have had heavy pesticide use in their watersheds, and some receive contamination from heavy metals and industrial contaminants. Several large Gulf sturgeon from the Apalachicola River have been found to have potentially detrimental levels of organochlorines and heavy metals in their tissues. While the effects of these contaminants are not certain, they are potentially detrimental to the sturgeon's survival.

The Service has carefully assessed the best scientific and commercial information available regarding the past, present, and future threats faced by this species in determining to make this rule final. Based on this evaluation, the preferred action is to list the Gulf sturgeon as threatened. The species has declined seriously throughout its range, and has been extirpated in some portions of that range. Although not yet an endangered species, it is likely to become one in the foreseeable future if further habitat loss or degradation occurs.

Critical Habitat

Section 3 of the Act defines critical habitat for an endangered or threatened species as the specific areas containing the physical and biological features essential to the conservation of the species. "Conservation" means the use of all methods and procedures needed to bring the species to the point at which listing under the Act is no longer necessary. Section 4(a)(3) of the Act, requires that, to the maximum extent prudent and determinable, the Secretary designate critical habitat at the time the species is proposed to be endangered or threatened. Service regulations (50 CFR 424.12(a)(2)) state that critical habitat is not determinable if information sufficient to perform required analyses of the impacts of the designation is lacking or if the biological needs of the species are not sufficiently well known to permit identification of an area as critical habitat. Section 4(b)(2) of the Act requires the Service to consider economic and other relevant impacts of designating a particular area as critical habitat on the basis of the best scientific data available. The Secretary may exclude any area from critical habitat if he determines that the benefits of such exclusion outweigh the conservation benefits, unless to do such would result in the extinction of the species.

In the May 2, 1990, proposed rule to list the Gulf sturgeon, the Service stated that designation of critical habitat was not prudent. The basis for this determination was that it would be impractical to designate critical habitat over an area as large as the Gulf sturgeon's range, especially when the exact areas utilized are not fully known. Though there are areas that likely are important to the Gulf sturgeon, they have not yet been identified. The species feeds over large areas of the Gulf of Mexico and spawns in most of the larger rivers draining into the eastern Gulf. Each major river system in the eastern Gulf is believed to support its own breeding population. The highly migratory, wide-ranging behavior of the Gulf sturgeon requires very large areas of coastal waters and these areas are not currently understood. It would be impractical to designate critical habitat over this large area and insufficient information exists to designate smaller isolated areas.

Consideration of a not prudent finding within the Service since the publication of the proposed rule has resulted in a determination that designation of critical habitat may be prudent for the Gulf sturgeon but is not now determinable. Section 4(b)(6)(C) provides that a concurrent critical habitat determination is not required, and that the final decision on designation may be postponed for 1 additional year from the date of publication of the proposed rule, if the Service finds that a prompt determination of endangered or threatened status is essential to the conservation of the species. The Service believes that prompt determination of threatened status for the Gulf sturgeon is essential. This will afford the species identify those physical and biological features that are essential to the conservation of the sturgeon and that may require special management considerations or protection and make a final decision on designation of critical habitat by May 2, 1992. In the interim, protection of this species' habitat will be addressed through the recovery process and through the section 7 jeopardy standard.

Federal agencies and activities likely to be affected by the listing of the Gulf sturgeon are discussed under "Available Conservation Measures" below.

Available Conservation Measures

Conservation measures provided to species listed as endangered or threatened under the Endangered Species Act include recognition, recovery actions, requirements for Federal protection, and prohibitions against certain practices. Recognition through listing encourages and results in conservation actions by Federal, State, and private agencies, groups, and individuals. The Endangered Species Act provides for possible land acquisition and cooperation with the States and requires that recovery actions be carried out for all listed species. Such actions are initiated by the Service following listing. The protection required of Federal agencies and the prohibitions against taking and harm are discussed, in part, below.

Section 7(a) of the Act, as amended, requires Federal agencies to evaluate their actions with respect to any species that is proposed or listed as endangered or threatened and with respect to its critical habitat, if any is being designated. Regulations implementing this interagency cooperation provision of the Act are codified at 50 CFR part 402. Section 7(a)(2) requires Federal agencies to ensure that activities they authorize, fund, or carry out are not likely to jeopardize the continued existence of such a species or to destroy or adversely modify its critical habitat. If a Federal action may affect a listed species or its critical habitat, the responsible Federal agency must enter into formal consultation with the Service.

Federal actions most likely to affect the Gulf sturgeon are the permitting programs and Federal water resource projects of the U.S. Army Corps of Engineers. Activities that would potentially involve section 7 of the Act include dredging of river channels, spoil deposition, and dam construction. Another potential section 7 involvement is pesticide registration by the U.S. Environmental Protection Agency. Following the proposal of the Gulf sturgeon as a threatened species, a

conference" pursuant to section 7(a)(4) of the Act occurred between the Fish and Wildlife Service and the Minerals Management Service, with regard to offshore oil leasing in the Gulf of Mexico."

The Act and implementing regulations found at 50 CFR 17.21 and 17.31 set forth a series of general prohibitions and exceptions that apply to all threatened wildlife. These prohibitions, in part, make it illegal for any person subject to the jurisdiction of the United States to take (includes harass, harm, pursue, hunt, shoot, wound, kill, trap, or collect; or to attempt any of these), import or export, ship in interstate commerce in the course of commercial activity, or sell or offer for sale in interstate or foreign commerce any listed species. It also is illegal to possess, sell, deliver, carry, transport, or ship any such wildlife that has been taken illegally. Certain exceptions apply to agents of the Service and State conservation agencies.

The above generally applies to threatened species of fish and wildlife. However, the Secretary has the discretion under section 4(d) of the Act to issue special regulations for a threatened species that are necessary and advisable for the conservation of the species. Take of the Gulf sturgeon is now banned in all States within the historic range except Georgia, where the species has been extirpated. Conservation and restoration of Gulf sturgeon stocks is already underway or planned by a combination of Federal, State, and private agencies.

In order to avoid unnecessary duplication of permitting requirements, the Service is promulgating a special rule allowing taking of Gulf sturgeon, in accordance with applicable state laws, for educational purposes, scientific purposes, the enhancement of propagation or survival of the species, zoological exhibition, and other conservation purposes consistent with the Endangered Species Act. Taking of Gulf sturgeon for purposes other than those described above, including taking incidental to carrying out otherwise lawful activities, is prohibited except when permitted under 50 CFR 17.32. The special rule will allow conservation and recovery activities for the Gulf sturgeon to be carried out without a Federal permit, provided the activities are in compliance with applicable State laws. Federal agency conservation activities involving Gulf sturgeon, however, will require consultation pursuant to section 7 of the Act, as discussed above.

On July 1, 1975, the Atlantic sturgeon (*Acipenser oxyrhynchus*, including the Gulf sturgeon) was included in Appendix II of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES). The effect of this listing is that CITES permits are required before international shipment may occur. Such shipment is strictly regulated by CITES party nations to prevent effects that may be detrimental to the species' survival.

Conservation and propagation work on the Gulf sturgeon is underway by the Service's Panama City, Florida, Fisheries Assistance Office; Gainesville, Florida, National Fisheries Research Center; Welaka, Florida and Warm Springs, Georgia National Fish Hatcheries; and by the private Caribbean Conservation Corporation, funded by the Phipps Florida Foundation. The Louisiana Department of Wildlife and Fisheries has initiated status surveys for the Gulf sturgeon and plans to expand this work. The Gulf States Marine Fisheries Commission's Technical Coordinating Committee agreed in 1989 that their Anadromous Fish Subcommittee would begin preparation of a management plan for the Gulf sturgeon during 1990.

National Environmental Policy Act

The Fish and Wildlife Service has determined that an Environmental Assessment, as defined under the authority of the National Environmental Policy Act of 1969, need not be prepared in connection with regulations adopted pursuant to section 4(a) of the Endangered Species Act of 1973, as amended. A notice outlining the Service's reasons for this determination was published in the Federal Register on October 25, 1983 (48 FR 49244).

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Author

The primary author of this rule is Dr. Michael M. Bentzien (see **ADDRESSES** Section).

List of Subjects in 50 CFR Part 17

Endangered and threatened species, Exports, Imports, Reporting and recordkeeping requirements, and Transportation.

Regulations Promulgation

PART 17—[AMENDED]

Accordingly, part 17, subchapter B of chapter I, title 50 of the Code of Federal Regulations, as set forth below:

1. The authority citation for part 17 continues to read as follows:

Authority: 16 U.S.C. 1361–1407; 16 U.S.C. 1531–1544; 16 U.S.C. 4201–4245; Pub. L. 99-625, 100 Stat. 3500; unless otherwise noted.

2. Amend § 17.11(h) for animals by adding the following, in alphabetical order under "Fishes" to the List of Endangered and Threatened Wildlife:

§ 17.11 Endangered and threatened wildlife.

(h) *

Species		Historic range	Vertebrate population where endangered or threatened	Status	When listed	Critical habitat	Special rules
Common name	Scientific name						
*	*	*	*	*	*		
FISHES							
*	*	*	*	*	*		
Sturgeon, Gulf	*Acipenser oxyrhynchus desotoi.*	U.S.A. (AL, FL, GA, LA, MS)	Entire	T	444	NA	17.44(v)
*	*	*	*	*	*		

3. Amend § 17.44 by adding paragraph (v) to read as follows:

§ 17.44 Special rules—fishes.

* * * * *

(v) Gulf sturgeon (*Acipenser oxyrhynchus desotoi*). (1) No person shall take this species, except in accordance with applicable State fish and wildlife conservation laws and regulations for educational purposes, scientific purposes, the enhancement of propagation or survival of the species, zoological exhibition, or other conservation purposes consistent with the Act.

(2) Any violation of applicable State fish and wildlife conservation laws or regulations with respect to taking of this species is also a violation of the Endangered Species Act.

(3) No person shall possess, sell, deliver, carry, transport, ship, import, or export, by any means whatever, any of this species taken in violation of applicable State fish and wildlife conservation laws or regulations.

(4) It is unlawful for any person to attempt to commit, solicit another to commit, or cause to be committed, any offense defined in paragraphs (v) (1) through (3) of this section.

(5) Taking of this species for purposes other than those described in paragraph (v)(1) of this section, including taking incidental to otherwise lawful activities, is prohibited except when permitted under 50 CFR 17.32.

Dated: August 5, 1991

Richard N. Smith,

Acting Director, Fish and Wildlife Service.

Dated: August 13, 1991.

Michael F. Tillman,

Deputy Assistant Administrator for Fisheries, National Marine Fisheries Service, National Oceanic and Atmospheric Administration, Department of Commerce.

[FR Doc. 91-23482 Filed 9-27-91; 8:45 am]

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Gulf Sturgeon Estuarine and Nearshore Marine Habitat Use In Choctawhatchee Bay, Florida

Annual Report for 1998

to the National Marine Fisheries Service and U.S. Fish and Wildlife Service

Dewayne A. Fox

North Carolina Cooperative Fish and Wildlife Research Unit

Department of Zoology

North Carolina State University

Raleigh, North Carolina, 27695-7617, USA

Joseph E. Hightower

North Carolina Cooperative Fish and Wildlife Research Unit

United States Geological Survey, Biological Resources Division

Department of Zoology

North Carolina State University

Raleigh, North Carolina, 27695-7617, USA

Introduction

Historically, Gulf sturgeon supported both substantial commercial and limited recreational fisheries throughout much of its range, which extended from Tampa Bay, FL west to the Mississippi River (U.S. Commission of Fish and Fisheries 1902, Burgess 1963, Lee et al. 1980). However, abundance has decreased substantially from historical levels due to overexploitation and habitat loss (USFWS, GSMFC, and NMFS 1995). The State of Florida prohibited harvest of Gulf sturgeon in 1984 and the species was designated as threatened by the U.S. Fish and Wildlife Service (USFWS) and National Marine Fisheries Service (NMFS) in 1991.

According to the Gulf sturgeon Recovery Plan, a critical step in the restoration process is to identify essential habitats in river basins, estuaries and nearshore marine waters (USFWS, GSMFC, and NMFS 1995). Most studies to date have focused on freshwater habitat (Huff 1975, Wooley et al. 1982, Wooley and Crateau 1985, Chapman and Carr 1995, Clugston et al. 1995, Potak et al. 1995, Carr et al. 1996a, Carr et al. 1996b, Marchant and Shutters 1996, Foster and Clugston 1997, Fox and Hightower 1998, Sulak and Clugston In press), and little work has been done on estuarine and neretic habitat requirements (Odenkirk 1989, Carr et al. 1996b). Much of our existing knowledge of marine and estuarine distribution comes from known incidental bycatch records provided by fishermen (Wooley and Crateau 1985). The Recovery Plan addresses this need by recommending the use of ultrasonic telemetry to monitor Gulf sturgeon movement patterns in estuarine and marine waters, where it is believed that most feeding and growth occurs (Mason and Clugston 1993, Carr et al. 1996b). Specifically recommended are collaborative studies between NMFS, USFWS, and NBS (now USGS) in order to identify fall and winter habitats. Once estuarine and marine distribution patterns have been characterized, habitat utilization studies can begin to better define essential habitat requirements (USFWS, GSMFC, and NMFS 1995).

This study is being conducted within Choctawhatchee Bay, Florida and nearshore Gulf of Mexico waters (Fig. 1). The Choctawhatchee River system is important because it supports a Gulf

sturgeon population that is genetically distinct from all other river systems (Stabile et al. 1996). In addition, the Choctawhatchee River is one of the few remaining relatively undisturbed rivers in Florida and has no obstructions to migration.

Study objectives include: (1) determining timing and distribution patterns of estuarine and nearshore marine use, (2) comparing used and available habitat to ascertain if habitat selection is occurring, (3) determining how sex and reproductive status influence estuarine distribution patterns. The results will also be compared to those of other Gulf of Mexico river systems to examine the importance of the estuarine component of Gulf sturgeon life history.

Methods

In conjunction with a previous research program to identify Gulf sturgeon spawning habitat, we collected fish that were large enough to be sexually mature (fork length > 1.3 m, Huff 1975). Large-mesh (25-36 cm) anchored gill nets were used to collect fish in the vicinity of Live Oak Point, Choctawhatchee Bay (Fig. 1) during March–April 1997 and March 1998 before the fish began their upstream migration. Soak times were limited to 4 hours in an effort to reduce incidental mortalities. Nets were fished 24 hours a day during favorable weather conditions. Captured fish were anesthetized (MS-222), measured (total length and fork length in cm) and weighed (g), and a small incision was made in order to determine the sex of the fish and to collect a small (<10 g) gonadal biopsy for later determination of reproductive state. Reproductive stages were classified on the basis of the histological results and individuals assigned to one of the following categories: immature, maturing, and ripe (Chapman et al. 1996).

During 1997, both a radio (Advanced Telemetry Systems model 5A, 40-41mHz) and ultrasonic (Sonotronics model CHP-87-XL, 35-38.4 kHz) transmitter were implanted into the abdomen of selected fish. In 1998, only ultrasonic transmitters were placed into fish. The transmitters have a guaranteed tag life of two years. The radio tags were used in the companion study to monitor the spawning migration while these fish were in the Choctawhatchee River.

Following tag implantation, the incision site was closed with sutures and the fish was injected with prophylactic antibiotics prior to release (Fox and Hightower 1998).

We conducted limited searches of Choctawhatchee Bay during the spring of 1997, before the fish migrated from the Bay into the River. The Bay was also periodically searched following the return of fish to the Bay in October-November of 1997. Beginning in early January 1998, the Bay was searched on weekly intervals until mid-June. During these searches, we listened for telemetered fish at intervals along transects that were spaced according to existing listening conditions. A similar approach was used within Albemarle Sound, NC, to establish habitat use and preference of telemetered striped bass (Haeseker et al. 1996). Additional searches of surrounding Bays (Escambia and Saint Andrew), Sounds (Santa Rosa and Big Lagoon) and nearshore Gulf of Mexico waters were made when time and weather permitted (Fig. 1). Jointly with the FWS, data-logging receiving stations were maintained (November-June) at the mouth of Choctawhatchee Bay and the Santa Rosa Sound entrance in order to detect migrations in and out of the Bay. These receivers were checked weekly for relocation information and to change batteries.

The following habitat parameters were recorded at locations of telemetered fish: substrate type, depth, turbidity, temperature (surface and bottom), and salinity (surface and bottom). In addition, the presence or absence of any potential prey items was noted during the collection of the substrate sample. Locations of telemetered fish were entered into a GIS database in order to examine habitat availability, use, and preference.

To examine the duration of estuarine-marine residence, we determined the date of river entry (migration from estuary to river). This date was estimated using a combination of radio and ultrasonic telemetry equipment, based on searches in the lower 110 kilometers of the Choctawhatchee River. Searches within the River began during early February 1997 and in early March 1998. These searches continued on at least a bi-weekly basis through early July during both years.

Results

In 1997, sampling for Gulf sturgeon began on February 20 and concluded on April 3. A total of 35 Gulf sturgeon were collected between March 3 and April 3 (Table 1). There were also two mortalities during these collections. Twenty fish (7 males and 13 females) were determined to be of suitable size, sex, and reproductive status for the implantation of transmitters (Table 2). Twenty-five sonic transmitters were purchased for this study; however, sampling ceased before the last five tags were implanted due to logistical conflicts with the spawning migration study. During 1998, sampling for Gulf sturgeon was limited by weather and tracking commitments. On March 26-27, a total of four fish were captured during one sampling trip (Table 3). Of these four fish, two were deemed suitable for transmitter implantation (Table 4).

Three of the telemetered males (42.9%) captured during 1997 were determined to be ripe with the remaining four classified as immature (Table 2). For females, one fish was classified as ripe (7.7%), one classified as immature (7.7%), and the remaining eleven fish were all classified as maturing (84.6%). Histological analysis of the biopsies from the 1998 fish are not yet completed but preliminary examination indicates that one fish was a non-ripe female while the other was a male of undetermined reproductive stage (Table 4).

During both years, most fish moved from the collection area and dispersed throughout the Bay or into the River shortly after tagging. Based on tag movement, there were no known tag expulsions or post-surgical mortalities during 1997. One of the fish (98-03) that received a ultrasonic transmitter in 1998 continued to move from the date of tagging (March 27) until May 15 (Table 4). Following this date, the fish remained stationary until the completion of the tracking period (mid-June). It seems likely that this fish has either died or expelled its transmitter. The relocations from this fish have been excluded from the analyses.

During 1998, weekly searches of Choctawhatchee Bay were made between mid-January and mid-June. As time and weather permitted, additional searches were made in the surrounding Gulf of Mexico, Santa Rosa Sound, Big Lagoon, St. Andrew Bay, and the Choctawhatchee River.

Additional searches of Escambia Bay, and both the Yellow and Escambia Rivers (Fig. 1) were made by Florida Department of Environmental Protection researchers in a complimentary Gulf sturgeon research program. A total of 200 relocations (Fig. 2) were made on 21 acoustically tagged Gulf sturgeon for an average of 9.5 relocations per individual. Of the 20 individuals that were tagged during 1997, 18 (90%) individuals were relocated during the 1998 sampling season (Table 5). This high return rate of fish tagged the previous year provides evidence that internal implants are an appropriate method of ultrasonic transmitter placement for long-term studies on Gulf sturgeon.

Weekly searches of Choctawhatchee Bay provided much information on Gulf sturgeon estuarine habitat use. Gulf sturgeon primarily occupied nearshore areas (Fig. 3). The mean depth at relocation sites was 2.8 m and fish were found in the 2-4 m depth strata the majority (54%) of the time (Fig. 4). In general, Gulf sturgeon were found primarily over sandy bottoms (53%) and were relocated infrequently in seagrass beds (Fig 4). Distribution within the Bay appears to be nonrandom. Fish were more frequently located in the eastern portion of the Bay, particularly in the area of Hogtown Bayou (Fig. 3 and 5). Relocations in deeper water were infrequent; Gulf sturgeon appeared to use the deeper Bay waters for moving between shoreline areas. Gulf sturgeon occasionally moved long distances rapidly (as evidenced by relocations of fish on consecutive days) but often remained in localized areas (<1 km^2) for prolonged periods. Substrate samples at relocation sites showed very low abundance of benthic macroinvertebrates. Bivalves and soft bodied marine worms (Annelids) were the only large (>1 cm) prey items that were found.

The timing of movement from the estuary into the River varied considerably among individuals. During 1997, the first fish departed the Bay on March 26 while the last moved upriver on June 26 (Table 2). In 1998, the first fish moved into the River on March 31 and three fish were unaccounted for in the River and were assumed to be either in the Bay or the Gulf on July 6 (last bi-weekly search effort) (Table 5). Interannual differences in the timing of river entry also varied considerably for individual fish (Fig. 6). A total of six males tagged during the 1997 season

returned to the Choctawhatchee River in 1998. Five of these six (83%) fish returned at an earlier date in 1998. The correlation between dates of river entry in 1997 and 1998 for males was marginally significant ($p= .11, r= .50$). For females, a total of 11 fish tagged in 1997 returned in 1998. We were able to determine date of river entry for 10 of the 11 fish. The remaining female (97-22) was relocated in the River for the first time on September 30. This fish was previously relocated in Choctawhatchee Bay on June 2. It is likely that this fish entered the River btween July 6 (date of last bi-weekly river search) and the end of September, although a specific date cannot be determined. Of those females for which date of river entry was determined, six of the 10 (60%) entered the River at an earlier date in 1998. Females exhibited no significant correlation ($p= .67, r= .02$) in the dates of river entry between years.

Our results also indicate that Gulf sturgeon are capable of entering the river on more than one occasion during their spring migration. During the last two field seasons, we have recorded three fish exhibiting this pattern. One male fish (97-08) moved between the River and Bay twice from mid-May through early June (Table 2). During the 1998 field season, two females (97-12 and 97-28) moved between the River and the Bay on several dates (Fig 7-8, Table 5). One of these fish (97-28) was recorded moving from the Bay to the River on three separate events. During this period from mid-March through mid-June, the fish encountered salinity changes of 10-20 ppt within 1-7 days (Fig 8).

During periodic searches of nearshore Gulf of Mexico waters, we failed to relocate any telemetered fish. However, other circumstantial results indicate that eight out of the 20 (40%) fish which received tags in the spring of 1997 occupied Gulf waters for extended periods of time. Prolonged periods of absence (defined here as > 6 weeks) from weekly search efforts combined in some cases with relocations at the remote receiver sites (located at entrance of Choctawhatchee Bay) suggest that fish were absent from Bay waters for extended periods of time (Fig. 7). Six of these fish (97-04, 97-12, 97-16, 97-22, 97-23, and 97-27) were documented returning to the Choctawhatchee River via the Bay. The final two fish (97-14, 97-34) are unaccounted for since

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Our hypothesis that Gulf sturgeon are foraging in shallow shoreline areas rather than the deeper portions of the Bay is supported by the distribution of infaunal macroinvertebrates (Livingston 1986). These potential prey items are lowest in abundance down the middle of Bay (deep waters with high silt levels) and in shallow areas characterized by sandy sediments. The probable causes for the observed low abundance in deeper waters are low dissolved oxygen levels and the high percentage of silt in the sediments (Livingston 1986). While we did not relocate many fish in the deeper parts of the Bay, the majority of our fish (53%) were relocated in areas which we classified as sand. These were the areas which were also classified as having low abundance of infaunal macroinvertebrates (Livingston 1986). A possible reason for this finding lies in the lack of rigor in which we assigned substrate type. We classified substrate visually while Livingston (1986) conducted quantitative particle size analysis to derive sediment composition. Perhaps some of the sediments which we classified as sand would be classified as a category with finer grain size (e.g. sand-mud, mud) using a more quantitative approach.

Other researchers have indicated that the primary period of growth for Gulf sturgeon occurs while they occupy the estuarine and marine components of their habitat (Mason and Clugston 1993, Clugston et al. 1995, Carr et al. 1996b). While we do not have many direct measurements of growth (via recaptures), we have been able to examine the gut contents of individuals which died during sampling. The digestive tracts of these individuals have been full of both ghost shrimp (*Lepedophthalmus louisianensis*) and an associated commensal shrimp (*Leptalpheus forceps*). Ghost shrimp are an oligohaline burrower that is found concentrated along intertidal and subtidal substrates which range from sandy mud to organic silty sand (Felder and Lovett 1989). The presence of ghost shrimp in the stomach contents of Gulf sturgeon and their absence in our benthic samples indicates that our method of sampling is not adequate for describing potential prey items. It is likely that our samples are not taken deep enough to collect the shrimp which can burrow deep in the soft sediments.

While we have not relocated Gulf sturgeons in Gulf waters to date, our results provide strong circumstantial evidence that adult Gulf sturgeon reside in the marine environment for extended periods of time, possibly for periods greater than one year in length. The absence of Gulf sturgeon from nearby rivers, Bays, and surrounding sounds for prolonged periods of time leads us to believe that these individuals are exiting the Bays and entering the Gulf of Mexico. Based on a limited sample size, it also appears that female Gulf sturgeon are more likely to enter the Gulf than males. Of the eight individuals which we hypothesize to have left Choctawhatchee Bay and entered the Gulf, seven (88%) were females. Migration into Gulf waters may be important for females since gonadal development has a higher energetic cost for females. Differences have been documented for both the Gulf sturgeon and the closely related Atlantic sturgeon for both condition factor and gonadosomatic index with regards to sex of the individual (Huff 1975, Van Eenennaam et al. 1996). Adult female Gulf and Atlantic sturgeons were found to have both a condition factor and gonadosomatic index that was significantly higher than that for males. Assuming the nutrient assimilation is the same between sexes, the increase in gonadal weight relative to body weight likely requires increased nutrients necessary for gonadal development. Our findings provide circumstantial evidence that adult female Gulf sturgeon are utilizing the Gulf of Mexico more than males and we hypothesize that foraging may play a role in this behavior.

Homing fidelity in Gulf sturgeon is thought to be high (Wooley and Crateau 1985, Stabile et al. 1996, Foster and Clugston 1997). This high degree of natal stream fidelity is proposed as the primary mechanism for observed genetic structure among remaining Gulf sturgeon populations (Stabile et al. 1996). To date, all records of straying among populations have been between the Apalachicola and Suwannee Rivers in Florida. The straying between these systems is thought to be the cause of their high degree of genetic similarity (Stabile et al. 1996). Alternatively, that straying has been documented between these systems may be due to the relatively high research effort that has been directed towards these rivers in comparison to other systems.

Although most of our fish have returned back to the Choctawhatchee River, one adult male (97-07) has been recently relocated in the Escambia River (>100 km from Choctawhatchee Bay) in a complimentary telemetry (Florida DEP) study of Escambia Bay and the Escambia and Yellow Rivers. This record of straying is especially interesting since the Choctawhatchee and Escambia River systems are thought to be distinct at the population level (Stabile et al. 1996). It had been thought that only juvenile and subadults would stray (Jim Barkalow, USFWS (retired), personal communication). However, this fish (97-07) was an adult male (classified as ripe in 1997) which was also found on documented spawning grounds in the Choctawhatchee River during 1997 (Fox and Hightower 1998).

During their movement from estuarine and marine waters into rivers, Gulf sturgeon reportedly require a period of physiological acclimation to changing salinity levels (Wooley and Crateau 1985, Carr and Chapman 1995). Our results indicate that adult Gulf sturgeon require very little time for such physiological acclimation. In the last two years, we have recorded three adult Gulf sturgeon moving from the upstream spawning grounds back into the Bay for periods of up to a month in time. It appears that Gulf sturgeon can move through the river/bay interface rapidly and require little if any time for acclimatization. These findings correspond well with the recent work of Altinok (1997) who determined that by age one, Gulf sturgeon have developed an active mechanism for osmoregulation and ion balance in a euryhaline environment.

Although overexploitation, habitat loss and degradation have been linked to Gulf sturgeon declines (Huff 1975, Wooley and Crateau 1985) we know very little about the role of anthropogenic impacts on sturgeon while they are in the estuaries and Gulf waters. We observed marked differences in habitat use within Choctawhatchee Bay that appear to be unrelated to depth, salinity or substrate. It will be important to determine whether heavily used areas (especially Hogtown Bayou) differ in some habitat characteristic not measured, or whether other apparently similar areas are degraded. Concerns also exist about declining habitat quality within the Gulf of Mexico. Although members of the genus *Acipenser* are thought to have adaptations to hypoxic

conditions (Burggren and Randall 1978), large areas of the marine benthic community in the Gulf of Mexico may be undergoing rapid deterioration due to hypoxic conditions (Malakoff 1998). Further progress on delineating Gulf sturgeon marine and estuarine distribution patterns should aid in predicting how declines in habitat quality will affect recovery efforts for this species.

Future plans for this project include documenting the timing of river departure beginning in the fall of 1998. Following the arrival of the fish in the Bay, weekly systematic searches of the Bay are planned. These searches will be weather dependent and if appropriate weather conditions are encountered, searches of the nearshore Gulf of Mexico waters will also be conducted. We also plan to re-deploy the two remote monitoring stations in the same locations as in 1997-1998.

Additional collection of adult Gulf sturgeon is planned for the winter of 1998 to find suitable fish for the remaining seven (3 remaining, 4 replacement) sonic tags. Attempts will be made to catch fish as early as possible during the winter months, in order to maximize the amount of time fish are resident in the Bay (before river entry). Since ripe females were not well represented in previous collections, sampling will be focused on capturing these fish if possible. If however, we are unable to collect ripe individuals early in the winter, we will then place transmitters into fish that are of appropriate size.

To gain a better understanding of Gulf sturgeon habitat requirements, we plan to begin systematically sampling both physical and biological parameters in the area of Hogtown Bayou. For comparison we also plan to select at least two other bayous in Choctawhatchee Bay which are not frequented by telemetered fish. We plan to set up monthly transects in each of theses sampling locales to examine the temporal aspects of both of prey abundance and physical parameters. The exact number of both transects and the sampling points along the transects will be determined later.

At each sampling location we plan to take a substrate sample with either a box-core or Van-veen grab as they are more suited to sampling in soft substrates. Substrate cores will be washed through a small mesh (.5 cm) screen to separate out potential prey items, which will be preserved

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Identification of Gulf sturgeon spawning habitat in the Choctawhatchee River System, Alabama-Florida

Final Report
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Dewayne Fox and Joseph E. Hightower

North Carolina Cooperative Fish and Wildlife Research Unit
Department of Zoology
North Carolina State University
Raleigh, NC 27695-7617

Introduction

Sturgeons (family: Acipenseridae) are limited to the northern hemisphere and occur in habitats ranging from fresh to saltwater. With few exceptions, sturgeons are thought to be particularly threatened by anthropogenic impacts due to their life history patterns (Rochard et al. 1990). Most species require many diverse habitats which, when coupled with a late age at first reproduction and a long maturation cycle, makes them very sensitive to perturbations (Waldman 1995). The declines in abundance of this ancient group of fish have been attributed to overexploitation (Birstein 1993, Boreman 1997), habitat loss (Kynard 1997) and to a lesser extent, pollution (Ruban 1997). At present, all extant sturgeon species can be considered threatened and several North America species are listed as endangered. Nonetheless, the prognosis for most North American species is generally considered to be better than that of their Eurasian counterparts (Birstein et al. 1997).

The Atlantic sturgeon, *Acipenser oxyrinchus*, is comprised of two disjunct subspecies along the Atlantic and Gulf coasts. These are the Gulf of Mexico form, *A. o. desotoi,* (hereafter referred to as Gulf sturgeon), and the allopatric East Coast form, *A. o. oxyrinchus* (referred to as Atlantic sturgeon for the remainder of this paper). Vladykov (1955) and Wooley (1985) examined the morphological characteristics of fish from the two areas and concluded that they warranted subspecies taxonomic recognition. Rivas (1954) proposed that the emergence of peninsular Florida and the warm waters of the Gulf stream which bound it provided a mechanism for the divergence. From a life history perspective, it appears that distinctions between the two exist to support this hypothesis (Huff 1975, Carr et al. 1996a, Bain 1997, Foster and Clugson 1997, Smith and Clugston 1997). In addition, Ong et al. (1996) found differences in mitochondrial DNA that support a subspecies designation for the Gulf sturgeon. Genetic studies have also shown that regional or river-specific populations of Gulf sturgeon exist throughout their present-day distribution (Stabile et al. 1996).

Gulf sturgeon have one of the southernmost distributions of sturgeon worldwide (Bemis and Kynard 1997). Historically, Gulf sturgeon ranged throughout the Gulf of Mexico from Louisiana to Cedar Key, Florida. However, they have been extirpated throughout much of their range and present distribution is from east of the Mississippi River to the Suwannee River, Florida (Reynolds 1993).

Historically, Gulf sturgeon supported both commercial and sport fisheries in Florida (U.S. Commission of Fish and Fisheries 1902, Burgess 1963, Smith and Clugston 1997). Overall, these fisheries showed many signs of overexploitation. Initial catch rates were frequently high in localized areas, followed by much decreased catch rates that often forced the harvesters to move to another river system (Huff 1975). In 1984, the state of Florida ended harvest in all state waters. This was followed in 1991 by Federal designation of Gulf sturgeon as a threatened species.

In an effort to prevent future declines and to bolster the current Gulf sturgeon population levels, the U. S. Fish and Wildlife Service and the Gulf States Marine Fisheries Commission completed a Recovery/Fishery Management Plan for the subspecies that identified the need to collect information on habitat requirements (U. S. Fish and Wildlife Service and the Gulf States Marine Fisheries Commission 1995). This plan specifically cites the need for information regarding the location, timing and site characteristics of essential spawning habitat. The report recommends the use of radio and ultrasonic telemetry in order to locate habitat that may be important for reproduction.

The NC Cooperative Fish and Wildlife Research Unit has conducted radio telemetry studies of Gulf sturgeon within the Apalachicola and Choctawhatchee rivers, FL. for the past five years. These tracking studies have been carried out in concert with other ongoing telemetry projects in the Suwannee River in an effort to better understand Gulf sturgeon habitat requirements (Chapman and Carr 1995, Foster and Clugston 1997). However, one disadvantage of the previous work is that the sex and reproductive status of tagged fish was not generally known. Chapman and Carr (1995) examined sex and reproductive status of

individuals prior to tag placement, but excluded male fish from their analyses, and did not report how the reproductive status of females influenced migratory patterns. Recent work on Atlantic sturgeon migration indicated that both the sex and reproductive status of individual fish can affect the migratory behavior of Atlantic sturgeon (Van Eenennaam et al. 1996). This information on the underlying mechanisms of migration is important to fisheries managers who are charged with the task of monitoring the recovery of Gulf sturgeon populations.

Evidence for differential habitat utilization in Gulf sturgeon based on sex and/or reproductive status is largely circumstantial at present. Shubina (1971) found that migration routes differed by sex for Sevryuga (*A. stellatus*). Huff (1975) noted that the low capture rate of spent females in surveys gave some support for the hypothesis proposed by Shubina. This idea of differential migratory patterns was also supported by the work of Carr et al. (1996b). Based on a multi-year sampling effort at the mouth of the Suwannee River, Carr et al. (1996b) reported that timing of river entrance is related to sex of individual sturgeon. This work suggests that there is a need to examine the roles that sex and reproductive status play on habitat selection.

Habitat requirements for successful spawning form a critical component of a fish's life history. Unfortunately, early efforts to delineate Gulf sturgeon spawning locations were largely unsuccessful. Huff (1975) was unable to collect eggs or larval sturgeon in one-meter plankton nets stationed near the bottom of the Suwannee River. In the Apalachicola River, some information on the location of spawning sites was derived by the capture of three Gulf sturgeon larvae (Wooley et al. 1982, Foster et al. 1988). Recent efforts to delineate Gulf sturgeon spawning habitat have been primarily through the use of artificial substrates to collect eggs (Marchant and Shutters 1996, Sulak and Clugston *In press*). Over a two-year period, Marchant and Shutters (1996) were able to collect Gulf sturgeon eggs at four discrete locations within the Suwannee River, FL. This provided the first insights into the location and timing of Gulf sturgeon spawning. Additional detail

regarding habitat characteristics of two Gulf sturgeon spawning locations has since been documented for the Suwannee River (Sulak and Clugston *In press*).

A combination of approaches have been used to identify spawning sites for other sturgeon. The collection of eggs and larvae via the use of artificial substrate, plankton nets, beam trawls and observation of spawning activity has provided insights into the spawning requirements for white sturgeon (*A. transmontanus*) (McCabe 1990, Parsley et al. 1993, McCabe and Tracy 1994). For shortnose sturgeon (*A. brevirostrum*), spawning sites have been characterized via the use of telemetry to examine movement patterns, and by netting to examine reproductive status of fish at hypothesized spawning sites (Buckley and Kynard 1985, Hall et al. 1991, Kieffer and Kynard 1993). Harkness and Dymond (1961) collected ripe lake sturgeon (*A. fluvescens*) with spears and were able to artificially propagate viable offspring from the spawn. From these results, they concluded that they had identified the spawning grounds for the lake sturgeon in Lake Nipgon, Canada. The presence of sturgeon eggs in the intestines of benthic fishes has been used to identify spawning sites for the Chinese sturgeon (*A. sinensis*) (Zhong-Ling and Yan 1991). Atlantic sturgeon spawning sites have been identified through the use of radio telemetry, capture of larvae, collection of ripe individuals, and levels of reproductive hormones and metabolites (Dovel and Berggen 1983, Van Den Avyle 1984, Van Eenennaam 1996).

Information on the spawning habitat requirements of Gulf sturgeon is an essential part of a recovery program for this species. With recent evidence showing genetically distinct subunits of Gulf sturgeon existing throughout the Gulf of Mexico (Stabile et al. 1996), efforts must be taken to examine spawning habitat and life history characteristics within individual river systems.

Our primary objective for the 1996-1997 field seasons was to delineate probable spawning sites for Gulf sturgeon in the Choctawhatchee River system, Alabama-Florida. This objective was addressed by tracking radio-tagged fish during the spawning season and deploying egg collectors in areas where telemetry evidence indicated that adult fish were

present (Marchant and Shutters 1996). A secondary objective was to examine the role that sex and reproductive status played on both movement patterns and habitat selection.

Specific objectives of this project were as follows:

1. Identify probable spawning sites for Gulf sturgeon within the Choctawhatchee River, Alabama-Florida via the use of radio telemetry, egg sampling and gonadal histology.
2. Compare habitat use during the spawning season with available habitat to determine if adult fish are preferentially using specific habitat.
3. Examine the distribution of available habitat to assess what factors might be contributing to spawning site location
4. Compare the results of this study with work conducted on other river systems and sturgeon species to evaluate the generality of the results.

Material and Methods

Study Area

The Choctawhatchee River originates in southeastern Alabama and flows southward approximately 280 km through Florida into Choctawhatchee Bay (Figure 1). The river drains a watershed in excess of 12,000 square km and has an average discharge of 198 m^3 which makes it the third largest river in Florida (Bass et al. 1980). The watershed is mostly agricultural or forested in nature with relatively low levels of urbanization, especially in the headwaters. The Choctawhatchee River is relatively unique when compared to other river systems in the Gulf of Mexico region due to the lack of impoundments on its mainstem. Two major tributaries contribute to the Choctawhatchee River, the Pea River in the northern portion of the watershed and Holmes Creek which is the major tributary in Florida. The Pea River is located almost entirely within Alabama and there is a run-of-the-river dam located on the Pea River at river kilometer (rkm) 191.

Sampling Location and Collection of Specimens

Netting operations were conducted both at the mouth of the Choctawhatchee River and within Choctawhatchee Bay, FL. Sampling was concluded when all transmitters had been implanted within fish large enough to be sexually mature (fork length >1.3m, Huff 1975) or when ripe fish were determined to be in the river. It should be noted that most fish captured during this study were implanted with one PIT tag and 2-4 Floy ® tags for external identification. These tags will assist in ongoing work which is focusing on the abundance and population structure of Gulf sturgeon in the Florida panhandle region. Fish numbers listed in this report were assigned on the order of collection.

In order to collect primarily adult fish, we used anchored gill nets deployed perpendicular to the shoreline so as to maximize the intercept area for migrating fish. During 1996, nets were typically set prior to dusk and checked periodically over the course of the night. All nets were pulled shortly after first light and checked for both fish and needed repairs. In 1997, weather permitting, nets were fished around the clock and checked at 4-hour intervals in accordance with collection permits issued by the Florida Dept. of Environmental Protection. Since soak times were low (<4 hours) and water temperatures were cool (<22°C), we expected to encounter very low mortality rates.

Fish Handling Procedures/Sample Collection

Captured fish were lifted into the bottom of the vessel, removed from the net, measured (both total length and fork length) to the nearest mm and weighed to the nearest 0.5 kg. All fish collected were examined for external Floy tags and checked with a PIT tag reader for the presence of PIT tags. We then placed fish into an anesthetic bath consisting of a mixture of tricaine methane sulfonate (tradename: MS-222) and bay water. Concentrations of the anesthetic bath were maintained at 50-100 mg/L (Harms and Bakal 1994) and the subject was constantly monitored (e.g. respiratory rate and ability to maintain balance) for anesthetic effects. Concentration levels were raised or lowered until the desired level of anesthesia was achieved.

Once the fish became fully anesthetized, an injection of Oxytetracycline (10 mg/kg) was given with a sterile syringe into the dorsal fin sinuses. No more than 4 ml was injected into any one site. Once the administration of antibiotics was complete, we then used a sterile heparinized syringe (21 gauge) to collect a 3-5 ml blood sample for quantification of steroidal hormone levels. Blood was drawn via the caudal vein in the area of the spinal column; insertion of the needle was just posterior to the anal fin and slightly off the centerline. Collected samples were then put into heparanized vials and placed on ice for subsequent sample preparation.

To explore the role of sex and reproductive status in Gulf sturgeon migratory behavior, we collected gonadal biopsies in order to determine the sex and reproductive status of individual fish (Huff 1975, Chapman et al. 1996). In addition to the gonadal biopsies, blood samples were also drawn from individual fish. We plan to analyze those samples in the near future to gain insights into the reproductive condition of a naturally occurring population of Gulf sturgeon. Such an approach would be less invasive than current histological methods. We plan to quantify levels of the sex steroids testosterone, 11-ketotestosterone and 17β-estradiol in addition to the egg yolk precursor vitellogenin in the blood plasma of Gulf sturgeon. This type of blood hormone analysis has been shown to be effective in the characterization of the gametogenic cycle of other sturgeons and teleost fishes (Jackson and Sullivan 1995, Van Eenennaam et al. 1996, Doroshov et al. 1997).

Surgical tools used during all procedures were maintained in a sterile condition until time of use. Field sterility was achieved via the use of a disinfectant bath (Nolvasan ® 2% solution). Before use, all instruments were washed with distilled water to remove the disinfectant. Instruments which were destined for reuse were placed back in the disinfectant solution prior to the next procedure.

A 40-mm incision was made using a surgical scalpel on the mid ventral line about 40-60 mm anterior to the insertion of the pelvic fin. This first incision penetrated just

below the skin and subsequent incisions were made with a combination of scalpels and blunt-tipped surgical scissors. Excess fluids were swabbed out of the incision with sterile swabs and gauze. We made every attempt to avoid severing blood vessels while incising deeper into the fish's musculature. Upon reaching the peritoneum, a retractor was placed into the surgical area to spread the musculature and allow for a clear view of the area. Care was taken while penetrating the peritoneum so as to minimize the risk of rupturing the dorsally located swim bladder.[1]

Gondal tissue was located by gently moving the other organs to one side with the use of a blunt probe. In the case of gravid females, it was unnecessary to search for the gonads as they were very apparent after the initial incision. After finding the gonadal tissue, its external appearance was noted and then a biopsy (1 cm^3 fragment) was drawn. Biopsies were taken either by an (8/0) aspiration needle or through a combination of surgical forceps and a scalpel. Each sample was preserved in a vial of buffered 10% formalin for histological analysis.

Since radio transmitters require external antennas due to signal attenuation, an additional incision was necessary. In this case, a large-gauge (8/0) sterilized needle was used to puncture the lateral body wall both lateral and posterior to the primary incision. The needle was advanced through the fish's musculature at an oblique angle such that it pierced the peritoneum just posterior to the original incision. Upon entering the peritoneal cavity, the transmitter antenna was threaded through the internal end of the needle and then forced down the needle length until it exited the fish. The sterilized radio transmitter was then placed into the body cavity and the needle removed. These microprocessor-controlled transmitters (Advanced Telemetry Systems model 5A) operated at 40 kilohertz and were programmed with two duty cycles (12 hour on/off in 1996, 24 hour in 1997) so that all transmitters were guaranteed to last throughout the 1997 field season. During 1997, ultrasonic transmitters (Sonotronics model CHP-87-XL) were also implanted in all fish

[1] Kynard, B. and Kieffer, M. C. 1994. Techniques for internal implantation of telemetry tags in sturgeon.

fitted with radio transmitters. The ultrasonic tags will be used in an ongoing research project to examine Gulf sturgeon estuarine and marine habitat use.

Beginning in 1997, both radio and ultrasonic transmitters were coated with Silastic® (Dow Corning Products) to reduce the probability of tag extrusion. The two-part elastomer was mixed and tags were then coated by dipping. Following the application of the elastomer, transmitters were then placed into a drying oven at 30°C until they were dry to the touch. Tags were then put into a sterilizing bath until time of implantation.

The incision was closed using sterile reabsorbtive suture material. To insure proper closure, a single interrupted suturing technique was applied. Surgical glue was placed over the incision site to aid in wound closure and to help secure the tag in place until the wound began to heal. Following the application of surgical glue, a thin layer of petroleum jelly mixed with Betadine® was placed over the incision area to protect against infection. We attempted to minimize the time from net removal to completion of surgical procedures in order to decrease stress levels on the fish.

Upon completion of tag implantation and sample collection, fish were monitored for signs of recovery (i.e., ability to maintain equilibrium and swimming actions) from the anesthesia. When recovery appeared to be complete, fish were lifted out of the anesthetic bath via the use of a modified stretcher for larger individuals or by hand for smaller individuals, and released near the site of capture.

A few externally-mounted radio transmitters purchased for other projects became available and were used to tag additional fish during this study. Those transmitters were programmed with a nine-months-on/three-months-off duty cycle and had a guaranteed tag life exceeding two years. External transmitters were attached at the base of the dorsal fin (Carr et al. 1996b) using a sterilized large gauge (8/0) aspiration biopsy needle. Teflon coated attachment wires were fitted through the hole and affixed in place with a backing

plate and crimps. Gonadal biopsies were collected through a small surgical incision for all fish fitted with external transmitters.

Telemetry

During 1996, tagged fish could only be located while in the river due to signal attenuation caused by the high conductivity water in Choctawhatchee Bay. Searches within the Choctawhatchee River began in 1996 two days following the release of the first radio-tagged fish. All navigable portions of the river were searched at least once each week. During 1997, fish were implanted with both radio and ultrasonic transmitters, so we were able to monitor their movements prior to river entry. Tracking in Choctawhatchee Bay was conducted periodically throughout the netting period and continued until all fish were found in the river. Tracking in the river began in early February in an attempt to document dates of river entry for telemetered fish. More emphasis was placed on searches in the upper portion of the river, as these areas were thought to be important for spawning. Nevertheless, all navigable portions of the river were searched at least biweekly until movement patterns indicated a probable end to the spawning season (i.e., ripe fish moving back down into the lower portions of the river). In both years, following the end of the spawning season, we attempted to locate all tagged fish once biweekly until early July.

During both field seasons, two crews were needed in order to conduct adequate searches once fish began to move into the upper Choctawhatchee. While one crew focused on upper river areas, the other crew was primarily concerned with documenting date of river entry and movement patterns in the lower river. In upper river areas, fish moved into both the Choctawhatchee and Pea rivers. The two rivers were searched on alternate days in an attempt to monitor fine-scale movement patterns.

Habitat Characterization

Fish positions were estimated (within 10 m) based on changes in signal strength using a paper clip, which served as a weak antenna. At each fish location, we recorded latitude and longitude using a hand-held GPS unit, and the position of the fish in the river (choice of banks, estimated distance from shore, etc.). Temperature, dissolved oxygen, conductivity, and salinity were measured at both surface and bottom using a YSI multi-meter. A substrate sample was obtained using a Petite PONAR® sampler. Samples were classified as either sand, silt, clay, cobble, rock and or detritus. Additional qualitative information on substrate hardness was determined through the use of a 5 m fiberglass pole which was pressed against the substrate. This method was much quicker than the PONAR unit and was employed when searching for hard bottom areas for deploying egg samplers.

We also recorded water temperatures once every 2.4 hours using a temperature logger at rkm 117. The site at rkm 117 was just below the confluence of the Choctawhatchee and Pea rivers. In 1996, the temperature logger was placed in the field during early March, shortly after fish began moving into the rivers. During 1997, the temperature logger was in place by early February, prior to the start of upriver migration. During both years, the logger operated continuously until retrieval at the end of the field season (mid-June 96, mid-July 97).

River flow rates were obtained from the U. S. Geological Survey gaging station (#02361000) located on the upper Choctawhatchee River. This gaging station was located at rkm 167 in the area of Newton, Al. Daily flow rates calculated by the gaging station were used to examine the interaction between flow rates and movement patterns.

Egg Collection

Since the primary objective of this project was to identify Gulf sturgeon spawning sites, egg samplers were concentrated in areas where telemetry evidence suggested that fish might be spawning. Previous results regarding substrate type (rock-cobble bottom) and flow patterns (flow > 1m/s) at spawning locations of Gulf sturgeon and other sturgeon

species were also taken into account when selecting sites for deploying egg samplers (Buckley and Kynard 1985, Marchant and Shutters 1996, Bemis et al. 1997, Wei et al. 1997). Samplers were also positioned in areas where current patterns (i.e., eddies) were thought to result in an accumulation of eggs (K. Sulak, Gainesville National Fisheries Research Center, personal communication). Egg samplers do not establish the exact location of spawning since little or no information is available on the spawning behavior or rate of egg sinking for Gulf sturgeon. Nevertheless, the collection of eggs does establish (at a minimum) that spawning was taking place upstream from the sampler position.

Egg samplers were based upon the design of Marchant and Shutters (1996). Sampling for eggs began when telemetry evidence suggested that mature fish were moving into areas where spawning was thought to occur (i.e., upstream hard bottom areas). Between 70 and 100 samplers were deployed in both rivers and examined every 24-72 hours for the presence of Gulf sturgeon eggs. For specific sites, the number of sampling pads deployed ranged between about 15 and 50 depending on the availability of samplers, desired size of sampling area and number of fish in immediate area. We measured depth, substrate type, surface turbidity, conductivity, temperature and dissolved oxygen at each location where a Gulf sturgeon egg was collected. When time permitted, the same parameters were measured for sites where eggs were not collected. Sampling for eggs continued throughout the spawning season until it appeared that most telemetered fish had left potential spawning sites and moved downriver towards areas typically occupied during the summer.

Data Analyses

A preliminary assessment of reproductive stage was made during the surgical procedure. Final categorization was based on histological examination of gonadal biopsies. Gondal tissue was stained with hematoxylin and eosin. Each sample was sectioned (3μ), mounted on a glass slide, and then examined using light microscopy. Following Chapman

et al. (1996), fish were classified as either "immature", "maturing", or "ripe". These terms are used when describing the reproductive stages of fish for the remainder of this paper.

A two-way analysis of variance (ANOVA) was used to examine the influence of sex and reproductive status on the migratory behavior of Gulf sturgeon. The analyses utilized year as a blocking effect to control for interannual variability. The second factor was a combination of sex and reproductive status (male-immature, male-ripe, female-immature, female-maturing, female-ripe). When significant differences were found in the whole model tests, contrast statements were developed to determine which factor levels were responsible for the difference. Response variables used in these analyses were maximum upstream distance migrated and date of river entry. Maximum upstream distance was defined as the maximum distance upstream from the river mouth that an individual fish was relocated during the course of sampling. We assumed that our searches enabled us to adequately characterize fish movement patterns. Distances upriver were determined by using geographic information systems software (ArcView version 3.0a, Environmental Systems Research Institute, Inc.). Date of river entry was defined as the date an individual fish was first relocated in the river. We attempted to correct for differences in the timing between river searches by rounding the date of entry to weekly intervals. Date of river entry was assigned as the last day of each weekly interval. All analyses were conducted at the 5% level of significance. Plotted least-square means are based on the fitted analysis of variance models (SAS Institute 1995).

Previous studies of Atlantic sturgeon have shown that individuals require prolonged periods between spawning events. Females were found to need between 3-5 years separating spawning events while males required 1-5 years (Smith 1985). Since the Gulf sturgeon reproductive cycle is not well documented at this time, we excluded from our analyses regarding reproductive condition any 1997 relocations of fish tagged in 1996, since the reproductive state of these fish would not be known.

Results

Collection of Specimens

Netting operations began February 21, 1996 at the mouth of the Choctawhatchee River. Following conversations with former sturgeon fishermen, operations were moved out into Choctawhatchee Bay where the probability of capturing adult Gulf sturgeon was deemed more likely. Sampling continued in Choctawhatchee Bay for the remainder of 1996 and throughout the 1997 field season. Gulf sturgeon were generally encountered along mud and or sand flats at depths of 2-6 m.

During 1996, sampling in the Bay commenced on February 23, with mature Gulf sturgeon collected on the first day of sampling. A total of 17 Gulf sturgeon were collected with at least one fish caught per sampling trip (Table 1). Of these 17 Gulf sturgeon, 15 individuals (6 males and 9 females) were fitted with radio transmitters (Table 2). One fish was released into Choctawhatchee Bay prior to surgical examination of gonads due to rough weather conditions that made surgical procedures impossible. One mortality occurred during 1996 sampling. Collection of Gulf sturgeon for radio telemetry concluded on April 3 after the last radio transmitter was assigned to a fish. None of the fish captured in 1996 had been previously tagged.

Sampling for the 1997 field season began on February 20; however, the first adult Gulf sturgeon was collected on March 3. A total of 35 Gulf sturgeon were collected in 1997 (Table 3). Unlike the previous sampling season, there were several trips when no Gulf sturgeon were collected. A subsample of 20 fish (7 males and 13 females) chosen on the basis of size, condition, sex and reproductive status received transmitters (Table 4). Fish not receiving transmitters were usually marked with external tags and an internal PIT tag then released.

Two fish died as a result of capture during the 1997 field season. One was a telemetered individual from the 1996 field season (Tables 1, 3). This fish decreased by 2.2 cm in fork length and 0.5 kg in weight at the time of capture. Based on a field necropsy, the digestive track contained large amounts of the ghost shrimp (Thalassinidea) and the overall condition of the fish appeared good. These factors, combined with the fact that the fish was measured and weighed on land the second time are evidence that the apparent decreases in length and weight were likely due to measurement errors.

Based on gonadal biopsies of male Gulf sturgeon, we found about equal numbers of ripe (n=6) and immature (n=7) fish. No males were collected that were classified as maturing. One male captured in 1996 and recaptured in 1997 was in ripe condition during both sampling periods. Based on gonadal biopsies of females, 14 were between spawning events (maturing state), 5 were ripe, and 3 were classified as immature. One female classified as ripe during 1996 was classified as maturing when recaptured during 1997.

Telemetry

In 1996, the primary radio-tracking period (> 1 trip/week) extended from February 26 until June 11. During this period, 14 of 15 tagged fish were relocated in the river on at least one occasion. A total of 193 relocations of telemetered fish were made during this period, with a mean value of 14 relocations per individual. The first tagged fish moved into the river on March 11, or 7 days after tag implantation and release (Table 2). The last fish was relocated in the river for the first time on September 4, or 188 days after release. The location of this fish established that post-surgery survival was 100% for the 1996 season.

Throughout the 1996 field season, we also searched for fish that had been tagged in 1995. Of five individuals fitted with external radio transmitters during the 1995 field season, two were relocated in the Choctawhatchee River during 1996 (Table 2). One of the three remaining tags was also relocated, but after several months of no movement, this tag was deemed shed.

The first relocations in the 1997 field season were on March 26, when 4 fish were found in the lower river. These fish had been at large from 4 to 13 days after tag implantation and release. Subsequent tracking of the mainstem river (<rkm 120) on March 31 and April 7, 1997 determined that two male fish from 1996 were already in the upstream habitat. A total of 230 relocations of fish that were radio-tagged in both 1996 and 1997 were made during the 1997 field season for an average of 9 relocations per individual. All fish that were radio-tagged in 1997 were found within the river. The location of the last two fish on June 26 established that, as in 1996, we achieved a post-surgery survival rate of 100%.

Of 17 fish that were released in either 1995 or 1996, 11 were accounted for during 1997 netting or telemetry searches. Five of these fish were equipped with external transmitters. Four of the five fish with external transmitters either shed their tags or were categorized as possible mortalities after several months of no movement. These included the two fish from 1995 that returned in 1996. One of these fish (95-4, Table 1) either lost its tag or died in early June 1996 at RKM 35. The transmitter attached to the other fish (95-5, Table 1), continued to move in the river until early September 1996. It is of interest, that this fish moved a considerable distance (>70 RKM) upstream from July to September, 1996. In early 1997 this tag was in the same location (RKM 113) as the previous year and was deemed non-useable. With the exception of the fish with an external transmitter that was recaptured during gillnetting operations (Fish 96-5 / 97-10, Tables 1 and 3), no fish with attached external transmitters were relocated during 1997. It should also be noted that, upon recapture, the backing plate on the external transmitter had cracked and the tag was not well attached. The external transmitter was removed and replaced with internal radio and ultrasonic transmitters.

A total of six fish equipped with internal transmitters during the 1996 season were relocated during 1997. One fish (96-1 / 97-1, Tables 1 and 3) tagged in 1996 died in our gill nets on March 3; the remaining 5 fish were tracked during the 1997 season (Table 5).

One of these five (96-7) was relocated occasionally at a site adjacent to the river mouth (rkm 0). This area was under tidal influence and conductivity levels often impaired transmitter reception. Since the location of this transmitter never changed, it was deemed an expelled tag or a possible mortality. Since this fish was found at RKM 30 during mid-August, 1996 and then in the area of the river mouth (RKM 0) during September, 1996, it seems likely the fish either died or expelled the tag on its return to the Bay. The four remaining fish were relocated in regular searches during the 1997 field season.

Migration Timing and Movement Patterns

Examination of telemetry results showed distinct patterns of riverine movement for Gulf sturgeon. The patterns did not vary significantly between years for date of river entry or maximum upstream distance (Tables 6 and 7). Significant differences between sexes were found for both the date of river entry and maximum upstream distance. In general, males entered the river earlier and were found to occupy habitats further upstream than females (Figures 2-4). Within each sex, there were also significant differences due to reproductive status in both the timing of river entrance and maximum upstream distance.

For female Gulf sturgeon, immature and maturing individuals entered the river significantly later than did ripe females. Ripe females entered the river during late March through mid-April while nonripe females entered the river over a much more protracted period of time (March-September) (Figures 2,3). It also appears that prior reproductive experience may play some role in the timing of river entry for Gulf sturgeon, as immature females entered the river significantly later than did maturing females (fish that have previously spawned but are between spawning events). There was no significant difference found between maturing and ripe females with respect to date of river entry.

Ripe female Gulf sturgeon moved significantly further upstream than did immature and maturing females (Figures 2-4). Unlike date of river entry, it appears that prior experience plays little role in the habitat utilized by non-ripe females (immature and maturing fish) during the spring migration. Immature and maturing females were found

not to be significantly different in terms of their maximum upstream relocation. Most ripe females were documented above the confluence of the Choctawhatchee and Pea rivers, whereas non-ripe individuals primarily utilized the lower portions of the river (Figure 5). This spatial separation was maintained during the late spring and early summer and was followed by a downstream movement of ripe individuals into areas that were occupied by immature and maturing fish (Figure 6). This pattern was very apparent in 1996 as all ripe individuals had moved downstream by mid-June. In 1997, this pattern was documented for the one ripe female tagged, but was somewhat confounded by later upstream movement of two maturing females (Figure 7).

The same patterns of migratory behavior were also observed for male Gulf sturgeon. Ripe males entered the river from early March through mid April; immature males entered significantly later (Figures 2,3). Additionally, ripe males moved significantly further upstream than did immature males (Fig 2,4). All ripe males were relocated above or within a few kilometers from the confluence of the Pea and Choctawhatchee Rivers (rkm 117) while most (5 out of 7) immature males remained in the lower river (Figures 6-8). Movement upriver by immature males was observed for two fish who moved to upriver areas where spawning had occurred. This upstream movement occurred after the end of the egg collection period and the probable end of the spawning season.

Ripe males tended to arrive earlier and remain for longer periods of time at upstream sites compared to females (Figures 6,7). Following departure of ripe females from the upper river areas, ripe males began moving downstream to lower river areas occupied by non-ripe and post-spawned individuals of both sexes. One ripe male was alternately located in the lower river and Choctawhatchee Bay during a two-week period in May and June 1997.

No clear relationship was found between timing of river entrance and flow patterns. Flow regimes varied considerably between 1996 and 1997 (Figure 6,7). During 1996,

flows were characterized by several pulses of high water from the middle of February though late April which then tapered off with the approach of summer. Flows in 1997 were high in late February and early March then generally low during early summer except for brief intervals of high flow.

Temperature patterns in the river also differed between years. In general, 1996 was characterized by cooler temperatures early in the year and a much more rapid warming trend with the arrival of summer when compared to 1997 (Figure 6,7). Temperature at time of river entry for individual fish ranged from 11.2 to 24.9 °C with a mean of 19.3°C for the 1996 field season. Water temperatures warmed earlier in 1997 then gradually increased as the year progressed. Accordingly, temperature at time of river entry was warmer (mean- 21.2 °C; range 18.3 -27.1°C) for 1997.

Egg Collection

During 1996, we chose not to deploy egg samplers when fish first arrived in areas thought to be suitable spawning habitat (i.e., hard bottom areas). Our intention was to wait until more than one telemetered fish congregated in a specific area. However, as the season progressed, telemetered fish moved over considerable distances within the upper river, with no obvious affinity for specific sites and no congregations occurred. We began deploying egg samplers near individual fish since other unmarked Gulf sturgeon could have been in the same area. Egg samplers were deployed between April 25 and May 16, 1996 on nine occasions. The number of samplers deployed at a given location varied between about 20 and 50, depending the location of the fish and the number of pads available. No eggs were collected on any egg samplers during the 1996 field season.

In 1997, we deployed egg samplers in selected upstream locations prior to the arrival of telemetered fish. Initially, we chose sampling locations based on telemetry results from 1996. As the season progressed and telemetered fish moved into the area, we also deployed samplers in areas where we either relocated telemetered fish or observed Gulf sturgeon rolling on the surface. Unlike the previous year, several telemetered Gulf

sturgeon remained in discrete areas for several days at a time in the upper portion of the river. Each of these areas was characterized by a steep limestone bank and hard bottom substrate. We sampled intensively in these areas where Gulf sturgeon appeared to be "settling out". Egg samplers were deployed continuously from April 4 through May 13. Except for a few periods of very high flow events (when samplers were submerged) in late April and early May, samplers were checked at 2-3 day intervals. A total of 42 fertilized Gulf sturgeon eggs were collected during 1997 at six locations in both the Choctawhatchee and Pea rivers (Table 8, Figure 9). All egg collection sites were located within the state of Alabama above rkm 110. The eggs were collected on six different dates between April 18 and May 1.

Microscopic examination of the eggs showed that the eggs varied in the amount of development. Developmental stages ranged between the morula and advanced gastrulation stage (Conte et al. 1988). Based upon temperatures at time of egg collection and information on hatching times for hatchery-reared Gulf sturgeon (Parauka et al. 1991), we estimate that all eggs were no more than 48 h old at the time of collection.

Gulf sturgeon eggs were collected primarily in hard bottom areas that were comprised of limestone and gravel. Depths ranged from 1.4 to 7.9 m at collection sites. Surface and bottom temperatures were essentially equivalent, with both ranging from 18.4 to 22.0 °C on dates when eggs were collected. Conductivity values ranged from 32-70 μmhos with a mean value of 46 μmhos. Turbidity values fluctuated greatly in response to the timing of rainfall. Values ranged from 12.3-114 NTU, with a mean value of 52.5 NTU.

Discussion

The collection of fertilized Gulf sturgeon eggs combined with telemetry results provide strong evidence that upper river areas are important for successful reproduction of Gulf sturgeon within the Choctawhatchee River Basin. Fertilized eggs were collected on

hard bottom areas in the upper river which were frequented by telemetered ripe Gulf sturgeon during the spawning season. We also established that Gulf sturgeon migratory patterns varied with respect to sex and reproductive status. This spatial and temporal separation of reproductive areas and adult-juvenile habitat has been observed for many other fish species (Wooten 1992).

Ripe individuals of both sexes entered the river earlier and moved significantly further upstream when compared to non-ripe fish. This strategy may allow for increased larval-juvenile survival (Carr et al. 1996). In addition, spawning in upstream areas may prevent the newly hatched larvae from coming into contact with saline water before they are ready to undergo the necessary osmotic changes required for this transition to the marine environment (Van Eenennaam et al. 1996, Altinok 1997).

We found that male Gulf sturgeon entered the river prior to females and remained at spawning sites for longer periods of time. Dovel and Berggren documented the same behavior in Atlantic sturgeon (1985) and Carr et al. (1996) provided evidence of a similar pattern for Gulf sturgeon. Our field observations also suggested that male Gulf sturgeon exhibited more movement during the spawning season than did females. In general, males appeared to be moving throughout the upper river, possible searching for females or suitable spawning sites. This pattern of movement was observed less frequently in females. Males were also recorded many kilometers further upstream than females during both years.

Gulf sturgeon began migrating into the Choctawhatchee River in late March and continued through the spring and into the summer months. The initiation of migration into the Choctawhatchee River appears to be delayed in comparison to the Suwannee River, FL, where migration was initiated in mid-February and concluded in early May (Carr et al. 1996, Foster and Clugston 1997). This difference in the start of migration is likely due to river-specific temperature differences, as the Suwannee River typically warms earlier than the Choctawhatchee (Frank Parauka, USFWS, personal communication). However, this

cannot fully explain the more protracted timing of river entrance that we documented for immature and maturing individuals.

A possible explanation for this difference in the timing of migration may be the location of capture sites. In previous studies on the Suwannee River, Gulf sturgeon have been collected at the river mouth (Huff 1975, Carr et al. 1996, Foster and Clugston 1997), whereas we collected Gulf sturgeon in the estuary prior to river entrance. The delayed start of migration that we observed for immature and maturing individuals is noteworthy when coupled with our observations that Gulf sturgeon appeared to be actively feeding within Choctawhatchee Bay. We hypothesize that mature non-spawning Gulf sturgeon may be utilizing estuarine habitat to a greater degree than previously thought. Since foraging ceases while adult fish are in the river (Clugston et al. 1993), extended periods of estuarine and marine residency may be important in rebuilding of gametes during non-spawning years.

Gulf sturgeon appeared to be foraging before initiating their upstream migrations. Several fish either regurgitated or passed fecal material containing large numbers of decapod crustaceans including blue crabs (*Callinectes sapidus*) and ghost shrimp (*Lepedophthalmus louisianensis*). Necropsy results for the fish that died during capture in 1996 indicated that the fish had been feeding exclusively on both ghost and commensal shrimps (*Leptalpheus forceps*) (Richard Heard, Gulf Coast Research Laboratory, personnel communication). All of these prey items are found within Choctawhatchee Bay.

Our results and those of Foster and Clugson (1997) support the hypothesis that Gulf sturgeon have adapted to erratic winter-spring flows and begin their migration when water temperatures approach some thermal minimum. The average water temperatures when ripe fish began migrating into the Choctawhatchee River were similar to those found for the Suwannee River (Foster 93, Chapman and Carr 1995). Similar to Foster and Clugston (1997), we did not detect evidence for a relationship between flows and the timing of river entrance. In contrast, Chapman and Carr (1995) found a strong positive

correlation between high discharge levels and the initiation of migration for Gulf sturgeon in the Suwannee River, FL.

Our results also suggest that the initiation of migration is more thermally regulated for fish that are reproductively mature ("ripe") since they enter the river during a narrower window of time when compared to immature-maturing ("non-ripe") individuals. These findings suggest that reproductively mature individuals are entering the river to time their arrival at the spawning grounds when river conditions will optimize the survival of eggs and larval sturgeon (15°-20°C, Chapman and Carr 1995). With the exception of one egg, all fertilized Gulf sturgeon eggs collected in this study were found at temperatures < 20°C.

Only 6 of 12 Gulf sturgeon receiving internal transmitters in 1996 were located in the Choctawhatchee River during 1997. This low return rate is somewhat problematic, given that Gulf sturgeon, unlike their Atlantic counterparts, are thought to return to rivers each year regardless of reproductive condition (Carr et al. 1996). The low return rate may be due to several possibilities including: straying to other river systems, remaining in the Gulf of Mexico or estuary, transmitter failure, or expulsion of the transmitter. Transmitter failure cannot be ruled out entirely but it seems unlikely that such a large number of tags would fail. Straying to neighboring river systems also seems unlikely since recent genetic evidence has shown that Gulf sturgeon show high fidelity to their natal rivers (Stabile et al. 1996). We suspect that the most likely possibility is for fish to remain in marine or estuarine waters for a year or more. The late summertime return of immature and maturing individuals provides evidence that a prolonged period of freshwater residency may not be required for all Gulf sturgeon. During our 1996 field season, one fish presumably remained in the estuary until early September after which it was relocated once in the lower river. During 1997, three fish were relocated in the bay (using sonic tags) until late June before migrating upriver. One Gulf sturgeon moved between the lower river and Choctawhatchee Bay on two occasions in late May and early June 1997. These movements between fresh and salt water habitats could not be detected in our previous telemetry studies

because only radio transmitters had been used. Ongoing studies to examine estuarine and marine distribution patterns should provide more insight into these patterns.

Information on Gulf sturgeon migratory behavior is necessary for the successful management of this species. For example, population estimates based on sampling riverine habitats will be biased if not all fish return to the river each year. Information about migration and the timing of reproductive cycles is needed in order to understand the impact of fishing on these populations.

Spawning periodicity in Gulf sturgeon is not known at present and much is inferred from work done on other sturgeon species. The finding of maturing males by Huff (1975) provided evidence that spawning was not annual for male Gulf sturgeon. However, our results suggest that male Gulf sturgeon are capable of spawning in consecutive years. We found no maturing males among the 13 males we surgically examined. The one male examined surgically in 1996 and 1997 was ripe in both years. We also obtained telemetry results for the two males who were ripe in 1996 and returned to the river in 1997. Both exhibited movement patterns in 1997 typical of ripe fish.

Our evidence regarding spawning periodicity in females shows that spawning is probably not annual. Histological results from the female recaptured in 1997 showed that this female was not ripe in consecutive years. This finding is also supported by telemetry evidence for other female Gulf sturgeon. In addition to the one recaptured female, two females which were fitted with transmitters during the 1996 field season returned in 1997. One was determined to be ripe in 1996 but, during 1997, exhibited movement patterns that were characteristic of a non-ripe individual (i.e., delayed river entry and reduced upstream movement). The second returning female was classified as immature in 1996, but exhibited movement patterns in 1997 more characteristic of a ripe female (i.e., early river entrance, migration further upriver, followed by a period of downstream movement to lower river locations). Our histological results also support a greater than annual interval

between spawning events. Three of 9 females in 1996 and 10 of 13 in 1997 were classified as maturing. These results are in agreement with those obtained by Huff (1975).

The upper river areas where ripe Gulf sturgeon were relocated and fertilized eggs were collected are characterized by steep bluffs and an increased prevalence of limestone substrate, when compared to the lower river sites, which contain predominantly sand. This change in substrate type occurs rapidly at around rkm 100. Information on Gulf sturgeon spawning in the Suwannee River also indicates that these areas of hard bottom are important for the successful Gulf sturgeon reproduction (Marchant and Sutters 1996; K. Sulak, Gainesville National Fisheries Research Center, personal communication). One possible explanation for spawning in hard bottom areas is due to the adhesive nature of Gulf sturgeon eggs. If these adhesive eggs were spawned in areas of soft bottom substrate (mud-sand), the eggs could quickly become encapsulated with a layer of material, possibly lowering the oxygen levels to the developing egg and resulting in suffocation.

We obtained fertilized Gulf sturgeon eggs on six dates between April 18 and May 1, 1997, although sampling was conducted both earlier and later in the season. Spawning in the Suwannee River occurs somewhat earlier (late March through early May) and seems to coincide with the timing of the lunar cycle. Gulf sturgeon eggs were collected in the Suwannee River shortly after the March and April new moons when water temperatures were below 20°C (K. Sulak, Gainesville National Fisheries Research Center, personal communication). We found little evidence for the coupling of spawning with lunar cycles within the Choctawhatchee River system. Eggs were first collected 11 days after the April new moon and collection continued on a semi-regular basis until just prior to the May new moon (May 6). These collections were made at different sites since we were more interested in identifying additional spawning locations than in quantifying the period of spawning at any one site. We sampled new locations based on past experience and relocations of telemetered fish whenever we thought our chances of egg collection were increased.

In summary, successful reproduction is critical if Gulf sturgeon are to recover to harvestable levels. Our results established that hard bottom areas in the upper river are critical for spawning. While it is likely that Gulf sturgeon spawn in other locations in the upper river, our telemetry results indicate that little or no spawning occurs in the lower portions of the river. In addition, as population levels rebuild, the need for suitable spawning habitat will also increase. For this reason, we must take care to preserve this habitat to insure the recovery of this species.

Conclusions

1. Fertilized Gulf sturgeon eggs were collected at six distinct locations in both the Choctawhatchee and Pea rivers. Collection sites were characterized by hard bottom substrate, steep banks and increased flows. All sampling sites were located within the State of Alabama above rkm 110.

2. Ripe Gulf sturgeon occupied these spawning sites from late March through mid May, which corresponds to the timing of egg collections.

3. We found significant differences between sexes in the timing of river entrance and maximum upper river relocation for Gulf sturgeon. In general, male Gulf sturgeon entered the river earlier, moved greater distances upstream and remained at spawning sites longer than did females.

4. Two patterns of movement were observed for female Gulf sturgeon. Ripe females entered the river significantly earlier than did immature females, although no significant difference was found between ripe and maturing fish. Ripe females also moved significantly further upstream when compared to immature and maturing females. Female Gulf sturgeon that migrated into the upper Choctawhatchee and Pea rivers to spawn moved downstream to lower river habitat at the end of the spawning season.

5. Clear differences were also present in movement patterns and timing of freshwater entrance for male Gulf sturgeon. Ripe males entered the river earlier and moved significantly further upstream than did immature males.

6. Results from gillnetting and telemetry support that male Gulf sturgeon may spawn annually while females require more than one year between spawning events.

7. Upper river hard bottom areas appear to be necessary for successful reproduction of Gulf sturgeon. Care should be taken to minimize habitat degradation or loss of these areas.

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Movement and summer habitat use of Gulf sturgeon in the Choctawhatchee River, Florida

Katherine Potak Zehfuss
Joseph E. Hightower
Dewayne Fox
National Biological Service
North Carolina Cooperative Fish and Wildlife Research Unit
Box 7617, North Carolina State University
Raleigh, NC 27695-7617, USA

Kenneth H. Pollock
Department of Statistics
Box 8203, North Carolina State University
Raleigh, NC 27695-8203, USA

Abstract

We studied the summer movements and habitat use of Gulf sturgeon *Acipenser oxyrinchus desotoi*, a threatened sub-species, during 1994 and 1995 by radio telemetry in a 148-km section of the Choctawhatchee River, Florida. A total of 30 Gulf sturgeon were affixed with radio tags following capture in Choctawhatchee Bay and in the mouth of the Choctawhatchee River during upriver migration in 1994 and 1995. We found that Gulf sturgeon tended to remain in five discrete areas in the lower-to-middle river, each about 2-3 km in length. Depth and flow did not appear to be critical habitat attributes, at least within observed ranges, as Gulf sturgeon remained in the same areas over a wide range of river depth (gage height) and flow levels. Gulf sturgeon distribution in the river appeared to be influenced by the presence of spring outlets and limestone outcroppings. We recommend further study of these discrete areas in order to determine the role that these habitats play in supporting Gulf sturgeon populations.

Introduction

The Gulf sturgeon, Acipenser oxyrinchus desotoi, is a sub-species of the Atlantic sturgeon, Acipenser oxyrinchus oxyrinchus (Vladykov 1955; Wooley 1985). It is found on the eastern Gulf of Mexico, from the lower Mississippi River eastward to the west coast of peninsular Florida, as far south as Tampa Bay (Wooley and Crateau 1982; Gilbert 1992). The Gulf sturgeon is an anadromous fish utilizing coastal freshwater rivers from early Spring through late Fall, and residing in the Gulf of Mexico the remainder of the year (Huff 1975).

At the turn of the century, annual commercial Gulf sturgeon catches in western Florida were almost 160,000 kg (U.S. Commission of Fish and Fisheries 1902). The fishery in the Apalachicola River declined from an average of 9,000 to 27,000 kg/year before 1917 to no substantial commercial fishing in 1976 (National Marine Fisheries Service 1977). In 1984, the State of Florida prohibited all Gulf sturgeon fishing due to serious declines in abundance (Rule No. 46-15.01, Florida Marine Fisheries Commission). In 1991, the Gulf sturgeon was listed as threatened in accordance with the Endangered Species Act (50 FR Vol, 56 49653-49658).

Despite the restrictions on harvest, in most rivers Gulf sturgeon populations have not rebounded, perhaps due to reduction of spawning habitat caused by dam construction, dredging, and pollution in the rivers (Livingston 1975; US Army Corps of Engineers 1978). Exploitation may still be a factor while Gulf sturgeon are in the Gulf of Mexico due to shrimp-trawl by-catch (Wooley and Crateau 1985). Also, Gulf sturgeon are long-lived, maturing late at about 7-12 years of age, and are thought to reproduce only every three to five years, all of which decreases their recovery ability (Huff 1975).

In Florida, populations of Gulf sturgeon are still found in the Escambia, Yellow, Choctawhatchee, Apalachicola, Ochlocknee, and Suwannee rivers (Reynolds 1993). However, the Suwannee River is thought to have the only large (N > 1000) and relatively stable population of Gulf sturgeon (Clugston et al. 1995).

Because the Gulf sturgeon is a listed species, the U.S. Fish and Wildlife Service (USFWS) has created and will be implementing a Recovery Plan that delineates reasonable actions required to recover or maintain Gulf sturgeon populations (USFWS and Gulf States Marine Fisheries Commission 1992). Among the recommended actions are investigations to locate and characterize critical habitats. For example, little is known about movement patterns and habitat requirements of Gulf sturgeon during summer (Van den Avyle 1984). This may be a critical period for Gulf sturgeon because of high summer water temperatures and the fact that Gulf sturgeon reportedly do not feed during summer and may lose a substantial percentage of their body weight (Mason and Clugston 1993). For that reason, the objective of this study was to characterize summer preferred habitat and movements within the Choctawhatchee River, which is one of the few remaining Florida rivers that is relatively undisturbed. To accomplish this objective, we intercepted Gulf sturgeon at the mouth of the river during their upriver spring migration. Telemetry techniques were used to observe movement patterns and to determine habitat preference.

Study Area

The Choctawhatchee River is the third largest river in Florida in terms of discharge (Bass and Cox 1988, Livingston et al. 1991). The river system is approximately 280 km long, 201 km of which lie in Florida. The Choctawhatchee River is not impounded, and has several large tributaries such as the Pea River in Alabama and Holmes Creek in Florida (Figure 1). The Choctawhatchee River primarily drains swamps, forested lands, and agricultural lands, with the latter causing the river to carry a heavy load of suspended solids. The river empties into Choctawhatchee Bay, where a delta approximately 5 km wide has formed. The USFWS Panama City Field Office verified the presence of Gulf sturgeon in the Choctawhatchee River through gill net surveys conducted during the 1960's and in 1988 and 1991.

Methods

1994 and 1995 Capture

Sampling in 1994 occurred on 14 occasions from March 21 to April 29. Gulf sturgeon were captured using fixed mono- and multi-filament gill nets from 3.1 m to 3.7 m deep and 45.7 m to 91.4 m in length. Mesh sizes ranged from 5.1 cm to 30.5 cm, with 6 to 8 nets used per occasion. Nets were set in the different tributaries of the delta at the mouth of the river and in Choctawhatchee Bay, about 100 meters from the mouth. We set nets at locations where commercial fisherman had historically caught Gulf sturgeon, or in channels thought to be migration routes. Set times ranged from 1.5 hours to overnight.

Upon capture, Gulf sturgeon were uniquely tagged with four external Floy tags, one placed in each pectoral and pelvic fin, and one internal Passive Integrated Transponder (PIT) tag placed in the base of the dorsal fin. Recapture information was recorded for any previously marked fish. Total length and weight measurements were recorded for all fish when possible. Since our boat was not equipped to weigh fish larger than 45.5 kg, the weights of larger fish were estimated using an existing Gulf sturgeon length-weight relationship (Huff 1975).

We stratified the application of radio tags across sizes of Gulf sturgeon and dates of capture in order to assess differences in movement and habitat preference due to size or date of entry into the river. As in other studies (Buckley and Kynard 1985; Hall et al. 1991), transmitters were attached with wire through holes drilled into two dorsal scutes. Twenty-one radio tags were 360-day transmitters, and four radio tags were smaller 90-day transmitters for use on smaller Gulf sturgeon. In order to increase the life of the transmitters so that telemetered fish could be followed for at least two years, twenty of the 360-day transmitters were programmed for a six-month on/six-month off duty cycle, and were initialized to turn on in March or April and turn off in October.

In 1995, sampling occurred on 9 occasions between April 5 and April 21. Gulf sturgeon were caught, tagged, and measured using the same procedures as in 1994,

except that more larger mesh nets (15.2 cm to 30.5 cm) were used and set times ranged from 3 hours to overnight. We fitted five Gulf sturgeon with external radio transmitters using the same methods as in 1994. Only fish greater than 130 cm total length received transmitters because they were also to be tracked in a concurrent study on Gulf sturgeon spawning habitat. All five 360-day transmitters were programmed for a nine-month on/three-month off duty cycle, set up to turn on in early March and turn off in November.

Telemetry and Utilized Habitat

In 1994, we searched the navigable section of the Choctawhatchee River at least once a week from May 4 to August 9, and then at least once every two weeks until October 13. Each search occasion lasted for one to four days. Since previous studies (Wooley and Crateau 1985; Odenkirk 1989) have found Gulf sturgeon to move more during spring and early summer than during midsummer, we searched more frequently during that time period. However, high flow conditions in July 1994 decreased the number of search occasions during that month due to safety concerns. We also searched several kilometers of the Pea River and further upriver from our study area on the Choctawhatchee River in May, Morrison Springs in June, and the navigable sections of East River in July.

As in previous studies (Wooley and Crateau 1985; Odenkirk 1989), Gulf sturgeon were initially located using a whip antenna, which was then replaced with a paper clip (which acts as a poor antenna) to determine the location within about 10 m. At the site where the signal was strongest, the position in degrees latitude and longitude was recorded using a LORAN unit. We noted the position of the fish relative to the channel and any visible habitat features nearby, such as tributaries, springs, or limestone outcroppings. In accordance with the precision of the telemetry equipment, habitat variables were measured within an approximate 10 m radius of the fish position. These variables were depth, conductivity, salinity, and dissolved oxygen and temperature at the surface and bottom. We also measured water velocity at the surface and at 20% and 80% of depth.

In 1995, we searched the navigable section of the Choctawhatchee River for telemetered fish at least once a week from April 20 to July 6 and then once every two to three weeks until November 1. However, high flow conditions in August 1995 decreased the number of search occasions during this month due to safety concerns. Each search occasion lasted one to two days. We also searched several river kilometers of the Pea River and further upriver from our study area on the Choctawhatchee River in May. When a fish was located, its position in degrees latitude and longitude was recorded using a Geographical Positioning System (GPS) unit. We used the same protocol as in 1994 for taking habitat measurements; however, our velocity meter failed in June so no subsequent velocity measurements were made.

Movement Patterns

Distances in river kilometers (RKM) were measured using a map wheel on U.S. Geological Survey (USGS) 1:24000 topographic maps. Geographical Information Systems (GIS) software PC ARC/INFO (Environmental Systems Research Institute, Redlands, CA) was used to determine in which RKM each relocation of a telemetered fish occurred. We considered the relocation of a fish to be independent of its previous relocation provided enough time had elapsed for the fish to move from one end of its home range to the other (White and Garrott 1990). Odenkirk (1989) had found Gulf sturgeon capable of moving 32.7 km/day, which means that Gulf sturgeon could potentially cover the entire 148 km section of the Choctawhatchee River in about four to five days. Using this information, we considered four or more days between each relocation to be a sufficient amount of time for relocations to be independent observations.

We pooled movement data by 5 km sections in order to provide adequate numbers of observations per category and simplify the presentation of results. Our examination of the movement data indicated that similar results would be obtained if narrower intervals were used. The RKM were pooled into the largest sections possible in order to decrease the number of categories used in the chi-square analyses, and to increase the expected values of the chi-square tests to at least 1.0 (Snedecor and

Cochran 1989). For the chi-square analyses, we further pooled RKM sections 21-30 and RKM sections 66-150 since Gulf sturgeon seldom used those areas.

To test for differences in Gulf sturgeon distribution among RKM sections between years, size classes, and dates of entry into the Choctawhatchee River, chi-square contingency tables (Snedecor and Cochran 1989) and chi-square tests of preference (Neu et al. 1974; White and Garrott 1990) were used. In order to reduce confounding variables, we determined whether there was a relationship between the time of entry into the Choctawhatchee River and fish size using linear regression. For the size analyses, we used two size classes (less than or equal to 130 cm TL versus those greater than 130 cm TL) based on the size at maturity as defined by Huff (1975). Only data from 1994 were used for these analyses since fish from 1995 represent only the larger size class. For the date-of-entry analyses, we used four groups from 1994 since there were three natural breaks in our capture dates creating one week intervals between the groups.

To test for differences in RKM use by month and in the distance moved by month, we also used chi-square contingency tests and chi-square tests of preference. We pooled search occasions over each month, and combined July and August in 1994 and 1995, September and October in 1994, and September, October, and November in 1995. High flow conditions in July 1994 and August 1995 decreased the number of search occasions during those months, so it was necessary to combine the two months in both years to obtain sufficient sample sizes. In addition, the river was searched only periodically in both years during September and October and during November 1995, which made it necessary to combine these months as well.

Available Habitat

We measured available habitat June 23 through July 3, 1995 along 148 cross-river transects located on the main course of the Choctawhatchee River, with one transect occurring at every RKM. The coordinates of each RKM were recorded in degrees latitude and longitude using a GPS unit. We measured the width of the transect using an optical range finder and recorded a profile of depth across the

transect using a chart-recording depth sounder. We sampled substrate from the middle of each transect using a ponar bottom sampler, and performed a visual inspection of substrate on the river bank at water level. The depth profile for each RKM transect was digitized using GIS software. Available depths were obtained by creating a database consisting of depths at 1.5 m intervals across each transect.

To compare the distribution of available depths to the depths where Gulf sturgeon were relocated, we had to account for differences in gage height (or river stage) between the period when sampling for available depths occurred and the dates when fish were relocated (Figure 2). We used USGS data on daily mean gage height (m) and water flow (m^3/sec) during 1994 and 1995 for two sites on the Choctawhatchee River at Caryville and Bruce, Florida (Figure 1). We standardized all depths by using as a benchmark the average gage height during the dates we measured available habitat. Because the majority of the relocations were between the Caryville and Bruce stations, we averaged the gage heights from the two stations for the dates we measured available habitat in 1995. We then calculated the deviation of gage heights from this benchmark for every date utilized and available habitat were sampled. We added the deviation for each date to the measured utilized or available depths on that date to obtain standardized depths. We determined whether Gulf sturgeon were selecting specific depth intervals by comparing standardized available depths with standardized utilized depths using chi-square tests and Bonferroni confidence intervals (Neu et al. 1974; Snedecor and Cochran 1989; White and Garrott 1990). To test whether Gulf sturgeon changed position in response to changes in river stage height, we compared the average gage height for the Caryville and Bruce stations to the utilized depth for each fish using correlation analyses.

To compare the change in flow rate with the distance a fish moved, we first averaged the daily mean flow for the Caryville and Bruce stations for 1994. For 1995, only flow data from Bruce station was available, so its daily mean flow was used. We then calculated the change in flow and the distance fish moved between search occasions, and tested the relationship between these variables using correlation

analysis.

Limestone Outcroppings and Springs

While searching for telemetered fish and measuring available habitat, we recorded which RKM had visible limestone outcroppings present. Locations of spring outlets in the Choctawhatchee River (Figure 3) were recorded using positions given on USGS 1:24,000 topographic maps and using locations recorded in Springs of Florida (Rosenau et al. 1977). We assessed how close Gulf sturgeon were to these features by calculating the distance from the RKM where a fish was relocated to the RKM containing the closest spring outlet and limestone outcropping. We also obtained expected distances from springs and limestone outcroppings by creating a random distribution of 500 RKM locations within our study section (RKM 1-148), and calculating the distances between these RKM locations and the nearest spring and limestone outcropping. Using chi-square tests for each year, we assessed whether Gulf sturgeon were found closer to springs and/or limestone outcroppings than expected.

Results

Capture

In 1994, 51 Gulf sturgeon were captured at the mouth of the Choctawhatchee River, ranging in size from 65 cm to 193 cm. One fish was captured twice, but there were no known recaptures of fish tagged in the 1988 or 1991 gill-net surveys. All fish were released upon capture and there were no known mortalities due to capture or handling. Radio tags were affixed to 25 Gulf sturgeon ranging in size from 74 cm to 193 cm. The first radio tag was applied on March 30 and the last on April 29.

In 1995, 13 Gulf sturgeon were captured, ranging in size from 100 cm to 197 cm. One fish was captured twice, but there were no known recaptures of Gulf sturgeon tagged in 1988, 1991, or 1994. All fish were released upon capture, and there were no known mortalities due to capture or handling. Radio tags were affixed to 5 Gulf sturgeon ranging in size from 139 cm to 197 cm. The first radio tag was applied on

April 14 and the last on April 19.

Telemetry

In 1994, the 25 radio-tagged Gulf sturgeon were found on 3 - 15 (mean=10) of the 17 search occasions. All relocations were in the main course of the Choctawhatchee River, with no fish found in any major tributaries.

In 1995, the five newly radio-tagged Gulf sturgeon were found on 12-16 of the 17 search occasions. Eight radio tags that were applied in 1994 were found in 1995. However, six of the eight radio tags were considered to be shed from fish since they were found in the same location as in late 1994 and no movement of the tag occurred during 1995. The two fish tagged in 1994 with tags still intact were relocated on two and four occasions during 1995. We excluded relocations of shed radio tags from our analyses, which resulted in a total of 245 relocations in 1994 and 82 relocations in 1995.

Movement

Gulf sturgeon were not found randomly throughout the Choctawhatchee River, and were most likely to be found in discrete areas (Figures 4-5). The five most frequently used areas were:

SHJ - near a tributary called Smokehouse Junction (RKM 11-15);

HW20 - below Highway 20 bridge (RKM 31-35);

RKL - below a tributary called Holmes Creek which provides an outlet for Cypress and Blue Springs, and is near the Rocky Landing boat ramp (RKM 41-45);

PSH - beside a park which we will refer to as Parkside Heights (RKM 51-55);

SPR - below a tributary called Sandy Creek which provides an outlet for Ponce de Leon and Jackson Springs, which we will refer to as Spring Outlet (RKM 61-65).

Areas HW20, RKL, and PSH were relatively long wide straight stretches with low-to-average velocities. The areas SHJ and SPR are narrower sections of the river characterized by sharp curves and average velocities. The areas RKL, PSH, and SPR

contain exposed limestone outcroppings, and the areas RKL and SPR are directly below known spring outlets.

We found a significant difference in the distribution of Gulf sturgeon among RKM sections between the two years ($p<0.001$). Gulf sturgeon used the lower river near the mouth more frequently in 1995 than in 1994, and area PSH more frequently in 1994 than in 1995 (Figure 5). In both years of the study, Gulf sturgeon preferred discrete areas SHJ and RKL, as well as areas PSH in 1994 and HW20 in 1995.

Because only 2 of the 25 Gulf sturgeon tagged in 1994 were found in 1995, we could not evaluate the extent of homing that occurred. However, both fish that were relocated in 1995 were within 2 km of where they were last located in 1994.

We found Gulf sturgeon to move greater distances upstream during the early summer and greater distances downstream during the fall in both years (Figure 6). Gulf sturgeon occasionally moved substantial distances upstream during the fall. The least amount of movement occurred during July and August in both years. During midsummer, Gulf sturgeon generally remained within the discrete areas, although there was some (apparently rapid) movement between areas. We seldom found fish between discrete areas (Figure 4).

The distribution of Gulf sturgeon over RKM sections varied significantly by time period in 1994 ($p<0.001$) and 1995 ($p=0.012$). Gulf sturgeon were found more frequently in the lower river near the mouth in May, in mid-river areas (RKM 31-55) in June-August, and throughout the river in September-November (Figure 7). Some differences between years were greater use of the RKL and PSH areas in 1994, and greater use of the HW20 and RKM 36-40 sections in 1995.

We found no evidence of a relationship between the length of Gulf sturgeon and date of entry into the river ($p=0.356$) (Figure 8). However, the length of fish did significantly affect which RKM sections were used ($p<0.001$). Larger Gulf sturgeon used area RKL more than smaller Gulf sturgeon, whereas the reverse was true for areas SHJ and PSH. Both size classes were most commonly found in area RKL.

We found the distribution of Gulf sturgeon over RKM sections to be affected by when fish entered the river ($p<0.001$). Earlier groups were more likely to move to upriver sites, while the later arrivals used the lower river near the mouth to a greater degree (Figure 10). The discrete area RKL was important to all groups.

We found no evidence of a correlation between the distance moved by radio-tagged fish from their last position and river flow rates ($r= -0.08$) in 1994 and in 1995 ($r=0.24$) (Figure 11). Most fish remained at the same location, even during periods of extreme flooding. In early July of 1994, the height of the Choctawhatchee River at Caryville rose approximately 4.5 m above flood stage (3.7 m). We had located 22 of the 25 radio tagged Gulf sturgeon on the occasion before the flood and, once searching could be resumed (on July 20), we found 20 of the 22 (86%) fish. One of the 20 transmitters was either shed or represented a mortality since it did not change position through the rest of 1994 and 1995. Of the 19 fish with functioning tags, 12 (63%) were within 1 km of their pre-flood position, with 8 of the 19 (42%) less than 0.5 km from their pre-flood position. The mean distance a Gulf sturgeon was found from its pre-flood position was 2.5 km (SE=6.86) downstream. The farthest a fish was found downstream of its pre-flood position was 95 km, while the farthest upstream was 54 km.

<u>Habitat</u>

We found that Gulf sturgeon tended to remain in position regardless of changes in river depth (gage height). The average correlation coefficient between the depths at which Gulf sturgeon were relocated and gage height ($r=0.43$) was significantly different from zero ($p<0.001$), and fifteen individual fish had correlation coefficients of 0.60 or greater (Figure 12). Some correlations were close to zero, however, which suggests that those Gulf sturgeon may have changed locations to maintain a specific depth as gage height changed.

We found a significant difference between available and utilized depths for both 1994 and 1995 ($p<0.001$), with Gulf sturgeon avoiding the shallowest areas (<2 m)

and occurring most commonly in water 2.0-2.9 m in depth (Figure 13). They were often found between the main channel and the river bank, instead of in the main channel which tended to be deeper. In 1994, 89% of Gulf sturgeon relocations were found outside of the main channel, and in 1995, 72% of relocations were outside of the main channel. We also found a significant difference in utilized depths between the two years, due to fish occupying deeper water in 1995 compared to 1994.

Limestone outcroppings and springs or spring outlets were found throughout the Choctawhatchee River, with a concentration of limestone outcroppings in the upper river and springs in the middle river (Figure 3). Our telemetry results suggested that Gulf sturgeon selected areas that were adjacent to or just downstream of either springs or limestone outcroppings. In both years, we found Gulf sturgeon 0-5 km downstream from a spring or spring outlet more frequently than expected, and more than 10 km upstream from a spring or spring outlet less than expected (Figure 14). In 1994, 27% of relocations were found within 2 km of a spring outlet, and 11% of relocations were found within 1 km. In 1995, 31% of relocations were found within 2 km of a spring outlet, and 13% of relocations were found within 1 km. The median distance from a spring outlet was 2 km downstream in both years.

Water temperatures at sites where Gulf sturgeon were located varied seasonally but were generally similar within each sampling occasion (Figure 15). In both years, the average temperature was 24.9 C from May to October.

We found Gulf sturgeon in 1994 to be 0-2 km downstream from a limestone outcropping more than expected, with 64% of relocations within 2 km and 52% within 1 km (Figure 16). In 1995, there was also a significant difference between the expected and observed distributions, but the sites selected were at considerable distances from limestone outcroppings. Only 27% of the 1995 relocations were found within 2 km of a limestone outcropping, with 21% within 1 km. The median distance from a limestone outcropping was 1 km downstream in 1994 and 9 km downstream in 1995.

When the distance from either a spring outlet or limestone outcropping was considered, relocated Gulf sturgeon were within 2 km more often than expected during 1994 (Figure 17). During 1995, Gulf sturgeon did not appear to associate closely with springs and limestone outcroppings. They occurred more often than expected only at distances of 8-9 km downstream.

Discussion

Gulf sturgeon within the Choctawhatchee River were often found during summer in one of several discrete areas in the lower-to-middle river, each approximately 2-3 km in length. Fish tended to either remain in one area for the entire summer, or display directed movements between areas. Foster and Clugston (in press) identified congregation areas approximately 4-8 km long for Gulf sturgeon in the Suwannee River. This pattern of site-specific summer movement has also been documented in other sturgeon species. Moser and Ross (1995) reported that juvenile Atlantic sturgeon exhibited slow movements during June-September, and tended to remain within deep holding areas (>10 m). Hurley et al. (1987) found that most of the long range movements of shovelnose sturgeon after spring migration were between discrete areas. For shortnose sturgeon, Buckley and Kynard (1985) noted direct and exact movement between discrete areas in the Connecticut River, and Dadswell (1979) found fish to become resident in certain areas until the fall.

We found that Gulf sturgeon within the Choctawhatchee River settled into one of the discrete areas by July in both 1994 and 1995. This is consistent with results obtained by Chapman and Carr (1995) and Foster and Clugston (in press), who found Gulf sturgeon in the Suwannee River to become established within specific areas by the beginning of July, and to move no more than one kilometer up or down stream from this established summer area. We also found several fish to move upstream in the fall of 1994, which could imply a fall spawning migration. Smith et al. (1984) also documented a fall upriver spawning migration of Atlantic sturgeon in South Carolina.

We found evidence that fish entering the river earlier were more likely to use areas farther upriver. During 1994, fish that entered the river in late March through mid-April were more likely to move into upriver areas, particularly the PSH area and RKMs 66-150. We did not detect substantial use of those areas in 1995, but gill netting and searching began later in 1995 than in 1994. Electrofishing studies in the upper Choctawhatchee River during 1995 confirmed the presence of Gulf sturgeon in the upper river prior to the start of our sampling. Thus the fish that we tagged in 1995 were not among the earliest migrants into the river. We hypothesize that Gulf sturgeon entering the river earliest are those most likely to spawn that year and that directed movement to upriver areas suggests that these areas may be spawning grounds.

Our low return rate in 1995 of fish tagged in 1994 could be due to Gulf sturgeon not returning to the same river every year, or due to transmitter failure or tags being shed while over-wintering in Choctawhatchee Bay or the Gulf of Mexico. We feel the latter explanation is most likely since 5 of our 25 tags were already shed while fish were still in the river in 1994. Straying to other rivers appears to be unlikely for Gulf sturgeon, based on the high return rates observed in earlier studies (Wooley and Crateau 1985; Odenkirk 1989; Foster and Clugston, in press).

In previous studies, habitat characteristics thought to be preferred by Gulf sturgeon have often been extrapolated from other sturgeon species, based on anecdotal evidence, or inferred from gill-net sampling (Wooley and Crateau 1985) or telemetry methods (Wooley and Crateau 1985; Odenkirk 1989; Foster and Clugston, in press). However, capturing fish in areas historically known to contain Gulf sturgeon may reduce the likelihood of detecting important new habitats. Also, capturing fish on suspected spawning grounds may provide a biased picture of habitat use, since non-spawning or immature fish may have different patterns of migration than spawning fish. Our approach of intercepting fish at the mouth of the river, then using movements data to identify areas of concentration, proved to be useful. We not only confirmed anecdotal information about known areas of concentration (SHJ, HW20, RKL) but also identified new areas not previously known to be important for Gulf sturgeon (PSH,

SPR). Both newly identified areas are in more remote locations, and were therefore less likely to be known to local residents.

It has been assumed that depth and velocity greatly influence habitat selection by Gulf sturgeon during summer. Wooley and Crateau (1985) describe summer habitat as being deep holes, and Dovel and Berggren (1983) assume Atlantic sturgeon seek deeper, cooler water in the summer. Moser and Ross (1995) found that juvenile Atlantic sturgeon tended to remain within deep holding areas during summer. Our results differed for the Choctawhatchee River, since most of the discrete areas selected by Gulf sturgeon were relatively shallow stretches (3-4 m) without deep holes. The Choctawhatchee River does have a deeper, higher-velocity main channel, but we found most Gulf sturgeon to be outside of the main channel, closer to the bank of the river. Our result also differ from the reported distribution in the Suwannee River, where Gulf sturgeon tended to be found within the main channel (Foster and Clugston, in press).

Depth and velocity do not appear to be primary factors in Gulf sturgeon habitat selection within the Choctawhatchee River. The depths selected by Gulf sturgeon were, for a majority of fish, positively correlated with river gage height. This indicates that Gulf sturgeon do not change position to remain in water of a specific depth. Gulf sturgeon did select against areas less than 2 m in depth, so there are apparent limits on the range of depths over which they exhibit no preference. We also did not detect any movement of Gulf sturgeon in response to changes in flow, indicating that fish remain in the same locations over a wide variety of flows. Foster and Clugston (in press) also saw no relationship between the behavior of radio-tagged fish and river discharge rates.

Previous studies have indicated that constant-temperature springs and limestone outcroppings may be important habitat attributes for Gulf sturgeon (Carr 1983; Wooley and Crateau 1985; Chapman and Carr 1995; Clugston et al. 1995; Foster and Clugston, in press). Our quantitative analyses of habitat preference within the Choctawhatchee River are consistent with these earlier studies. We find that Gulf

sturgeon exhibit a preference for areas downstream of spring outlets, although they do not occupy sites that have temperatures characteristic of springs. The average temperature at sites during May-October where we relocated Gulf sturgeon was 24.9 C, which was almost identical to the mean temperature reported for midsummer sites occupied by Gulf sturgeon in the Suwannee River (24.7 C; Foster and Clugston, in press). For both river systems, the observed summer temperatures were considerably higher than the expected temperature of spring water (about 21C, Racine et al. 1978). The Choctawhatchee River is primarily spring-fed, with spring water entering the river either from direct spring outlets, tributaries from springs to the river, or from seepage from the limestone outcroppings present in the river. However, due to the high flow of the river, thermal plumes due to spring water entering the river are very localized. Clugston et al. (1995) were unable to demonstrate, using temperature-sensing transmitters, that Gulf sturgeon in the Suwannee River moved into areas with temperatures characteristic of spring water. They also noted that the 21 C water discharged from springs within the Suwannee River mixed rapidly with ambient river water, so that only a small cool-water plume would be available as a thermal refuge. It is also possible that periodic movements into localized areas of cool water might go undetected (Foster and Clugston, in press).

Our results regarding the importance of limestone outcroppings within the Choctawhatchee River were inconsistent. Almost all the discrete areas where Gulf sturgeon settled contained a limestone outcropping, and 64% of the relocations in 1994 were within 2 km of an outcropping. During 1995, however, we did not detect a higher than expected concentration of fish in areas close to limestone outcroppings. Wooley and Crateau (1982) identified limestone shoals in the Apalachicola River as probable spawning grounds, and further work is needed to establish their importance in the Choctawhatchee River system. They may provide a substrate that eggs will readily adhere to, or may also seep mineral-laden water which attracts Gulf sturgeon.

Recommendations

We recommend further study of the discrete areas within the Choctawhatchee River that contained Gulf sturgeon. Detailed analyses of those areas could establish what factors (e.g., temperature, substrate, food resources) cause fish to concentrate in those areas. We also need to determine whether any of the discrete areas are used for spawning, in order to delineate all critical habitats of Gulf sturgeon. The Choctawhatchee River remains open to the possible long-term deterioration that has characterized many of the rivers in south Florida (Livingston et al. 1991), and we need to act to ensure the continued survival and eventual recovery of the Gulf sturgeon population in this river.

We also recommend applying our methodology to populations of Gulf sturgeon in other rivers. By radio tagging Gulf sturgeon at the mouth of these rivers during their spring upriver migration, it is possible to get an unbiased picture of the important habitats within each river. This will allow us to better protect Gulf sturgeon critical habitat in the event of future plans to alter (e.g., channelize, dredge, impound) any of these rivers.

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FLOODPLAIN FORESTS SPECIAL ISSUE

The hydrological and geomorphological significance of forested floodplains

ANGELA GURNELL *School of Geography, University of Birmingham, Edgbaston, Birmingham B15 2TT U.K.*

Abstract. Within river corridors, the distribution of plant species and communities is heavily influenced by hydrological and geomorphological processes. Furthermore, the vegetation can have a direct influence on the detailed character and rate of hydrogeomorphological processes. This paper reviews such interactions at a variety of spatial scales ranging from vegetation gradients across entire floodplains from hillslope to river channel, to the local influences of bank vegetation and in-channel accumulations of woody debris.

Key words. Hydrology, fluvial geomorphology, riparian vegetation, biogeomorphology.

INTRODUCTION

An understanding of the relationship between plants and characteristics of their immediate hydrological environment has long been a major research interest of plant ecologists. However, research on the larger-scale relationships between vegetation and hydrogeomorphological processes is a more recent and interdisciplinary development. Early work, by Hack & Goodlett (1960) on the relationship between vegetation, topography and hydrological processes, by Zimmerman, Goodlett & Comer (1967) on the influence of vegetation on the channel form of small streams, and by many authors on forest hydrological processes (e.g. the symposium edited by Sopper & Lull, 1967), represent a focus which developed gradually through the 1960s and 1970s to become a major theme for interdisciplinary research in the 1980s and 1990s. A number of books and review articles (e.g. Viles, 1988; Thornes, 1990; Malanson, 1993; Gurnell, 1995; Hupp, Osterkamp & Howard, 1995) testify to the breadth and strength of research in this area, and illustrate the interdisciplinary approach that has been essential to progress.

This paper concentrates upon forest vegetation within river corridors. It attempts to identify both the direct influences of vegetation on fluvial processes and the more indirect information that is provided by the vegetation (through its age, species composition and vigour) about floodplain environmental processes. This paper reviews the hydrological and geomorphological information contained within the distribution and character of vegetation on floodplains supporting a semi-natural forest cover.

INTERACTIONS BETWEEN HYDROGEOMORPHOLOGICAL PROCESSES AND VEGETATION

The distribution of plant species and communities within riparian and floodplain zones reflects the sensitivity of the vegetation to a variety of characteristics of the physical environment including: the degree and frequency of waterlogging; the energy and frequency of flooding; soil and river water quality; the calibre and organic content of river corridor sediments; and the rate of sedimentation. It may also reflect certain properties of individual plant species such as: seed dispersal mechanisms and requirements for germination; ability to survive transfer from sites of erosion to sites of deposition; ability to compete under particular environmental conditions and/or stages of vegetation colonisation and succession; and ability to survive the abrasive effects of specific flow velocity and sediment transport regimes.

Thus we may anticipate a close association between the processes which control the physical character of the river corridor environment, particularly the distribution of hydrological processes and fluvial

HILLSLOPE FLOODPLAIN CHANNEL

← Soil water hydrology ——

—— Inundation frequency →

—— Fluvial geomorphological processes →

Fig. 1. A gradient in the relative dominance of hydrogeomorphological processes across floodplains.

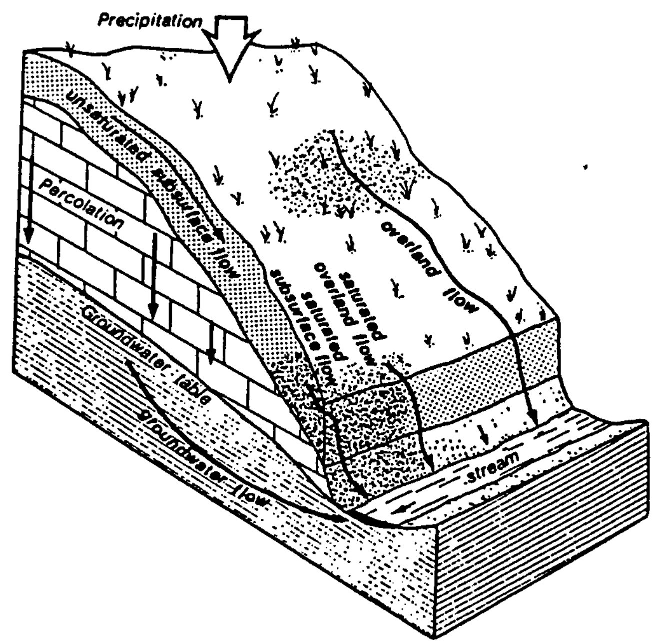

Fig. 2. Hillslope runoff processes (from M.D. Newson (1994) *Hydrology and the river environment*, p. 60; reproduced with permission of Oxford University Press).

geomorphic features, and the mosaic of river corridor vegetation. Furthermore, from the point of view of the hydrologist and geomorphologist, these process–vegetation interactions can lead to patterns in the vegetation which can reveal the nature and relative importance of hydrogeomorphological processes at different locations and spatial/temporal scales.

HYDROGEOMORPHOLOGICAL GRADIENTS ACROSS FLOODPLAINS

In order to comprehend the hydrogeomorphological significance of river corridor vegetation patterns, it is first necessary to consider the context of our present

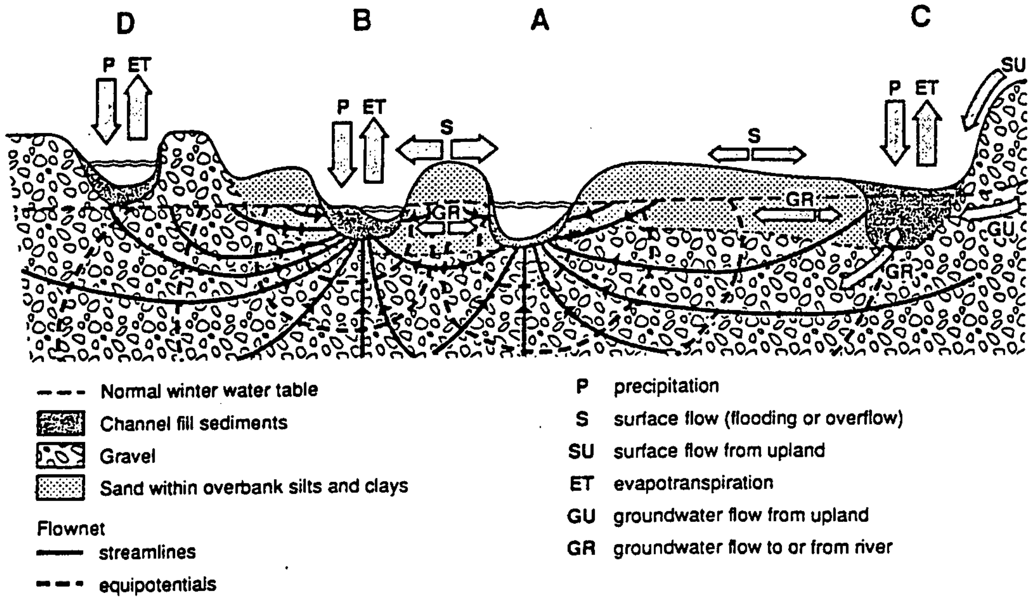

Fig. 3. A model of floodplain groundwater and soil water movements (reproduced with permission of the authors from A.G. Brown & C. Bradley (1995) Past and present alluvial wetlands and the eco-archaeological resource: implications from research in East Midland Valleys, UK. *Wetlands: archaeology and nature conservation*, (ed. by M. Cox, V. Straker and D. Taylor), pp. 189–203, HMSO, London).

understanding of the hydrogeomorphology of river corridors.

In simple terms, we can consider a gradient in the relative dominance of hydrogeomorphological processes across floodplains and the significance of such a gradient for vegetation patterns (Fig. 1). Thus any floodplain cross-section represents the result of current and past spatial transitions between hillslope processes (dominated by the relative importance of overland and subsurface flows of water) and fluvial geomorphological processes (dominated by the river flow and sediment transport regime) and morphological adjustments to these regimes. The intervening floodplain experiences a range of interactions between hillslope hydrological and fluvial geomorphological processes.

Thus we can consider three simple models which relate to hillslope–floodplain hydrological and river channel geomorphological processes.

1. A hillslope hydrological model (Fig. 2), which is representative in this diagram of the interactions between hydrological processes controlling a dynamic contributing area on temperate hillslopes. The model illustrates the importance of topography, infiltration capacity and hydraulic conductivity of the rock, superficial deposits and soil on hillslope drainage. Under a semi-natural vegetation cover, different hillslope plant communities can be shown to be sensitive indicators of the soil–groundwater regime.
2. A hydrological model of floodplain groundwater and soil water movements (Fig. 3) illustrates the significance of the subdued topography and the hydraulic conductivity of the floodplain materials in governing the soil water hydrological regime. Local variations in hydraulic conductivity and microtopography are associated with the character of marginal colluvial deposits, processes of vertical overbank floodplain accretion during flood events and in or near channel processes of sediment erosion and deposition. The differences in the soil water hydrological regime (which is dependent on contributions from different water source areas, micro-topography and hydraulic conductivity), can be reflected in marked differences in the overlying vegetation.
3. A typology of large river channels (Fig. 4) shows how the planform pattern, mobility and in-channel

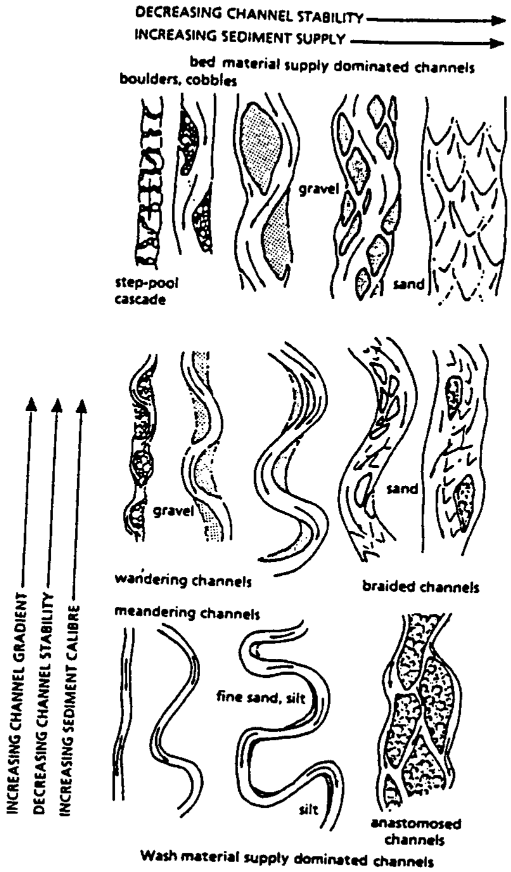

Fig. 4. Morphological types of large channels (reproduced with permission from M. Church (1992) Channel morphology and typology. *Rivers handbook*, Vol. 1 (ed. by P. Calow and G. E. Petts), p. 136. Blackwell Scientific, Oxford. The diagram is based on concepts from Schumm, S.A. (1985) Patterns of alluvial rivers. *Ann. Rev. Earth Planetary Sci.* **13**, 5–72, with permission from Annual Reviews Inc., and Mollard, J.D. (1973) Air photo interpretation of fluvial features. *Proceedings of the 7th Canadian Hydrology Symposium*, pp. 341–380).

geomorphological features of river channels reflects the interaction between stream power (discharge and gradient), sediment quantity and calibre. Lateral movement by the channel will leave a floodplain developed by lateral accretion that has a morphology and sedimentary structure which reflects the channel type that built it. The resulting variations in microtopography and hydraulic conductivity, plus the time since deposition, and the stresses and sedimentation caused by contemporary hydrogeomorphological processes, can each be reflected in the vegetation which colonizes the new floodplain and the subsequent succession that is observed. In association with forested floodplains, the influence of woody debris on flow hydraulics, sediment storage and transport, flow avulsion and channel pattern evolution can also be very significant.

The interaction between hydrological and fluvial processes leads to the development of different types of floodplain which have been classified by Nanson & Croke (1992) (Fig. 5). Here the classification is based on stream energy (reflected in discharge, slope and degree of confinement of the flow) and on the cohesiveness of the materials from which the floodplain is built. Each of the floodplain types can be expected to develop characteristic assemblages of vegetation.

Floodplain forests develop through interactions between the vegetation and the physical processes that are active. This review will illustrate, by reference to examples from forested river corridors, the significance of those interactions.

THE SOIL WATER REGIME

Contrasts in the soil water regime can exert a very strong primary control upon river corridor vegetation patterns. In humid areas, subtle relationships between soil water regime and vegetation have been widely demonstrated. For example, Osterkamp *et al.* (1995) review research on the relationship between vegetation, topography and hydrology within forested catchments in the United States. They also suggest for the Little River Basin, Virginia, a complex relationship between tree species, slope aspect and form, and local factors such as soil texture, shading, and litter, which may impact on evaporation loss and groundwater seepage. This example concentrates on hillslopes bordering a headwater river system where true floodplains do not exist. In situations where floodplains are more extensive, the association between topography, sediment calibre and vegetation, that is driven by differential soil water drainage, is more clearly defined. As a result, several researchers have found elevation to be the best explanatory variable for the distribution of herbaceous species within forests on floodplains in humid environments (e.g. Barnes, 1978; Menges, 1986). In more arid environments floodplains can still support forests, but here the sensitive association between soil

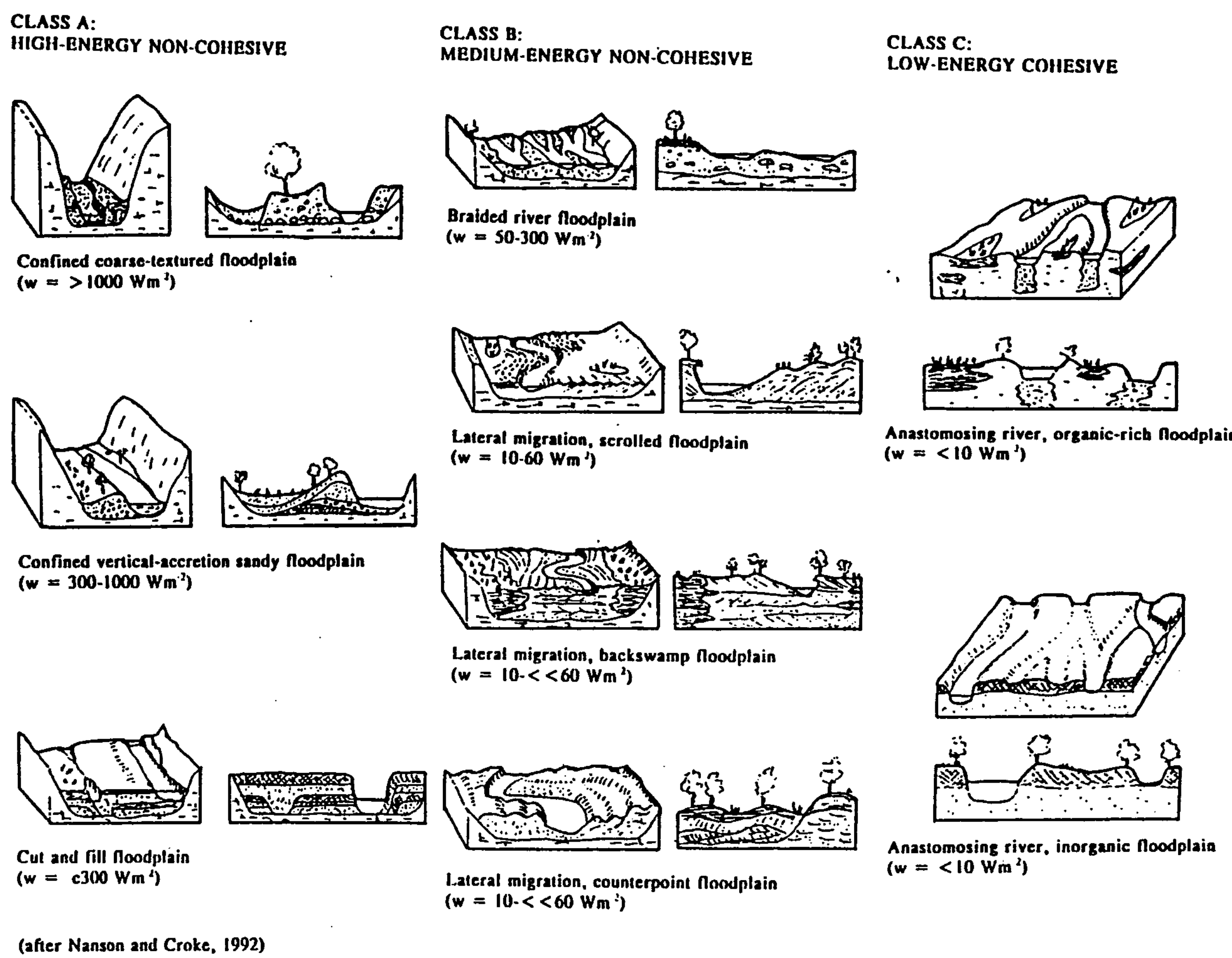

Fig. 5. A classification of floodplains (based upon G. C. Nanson and J. C. Croke, 1992; reproduced with permission of Elsevier Science – NL, Sara Burgerhartstraat 25, 1055 KV Amsterdam, The Netherlands).

water regime and vegetation generates even clearer boundaries in the vegetation. For example Zimmerman (1980, cited in Hupp, 1988), showed that the strong contrasts in water table levels and their seasonal variability across floodplains in Arizona were reflected in a sequence of valley floor vegetation ranging from dry scrub to a well-developed woodland cover. In such arid areas, a change in soil water regime can induce very marked changes in vegetation cover. For example, Groeneveld & Griepentrog (1985) demonstrated a decline in riparian forest cover along the lower Carmel River, California, which they attributed mainly to groundwater abstraction, although other factors may have been influential, including sediment transport change and channel incision following the closure of an upstream dam.

INUNDATION FREQUENCY

In addition to soil and groundwater influences, overbank flows can have a significant effect on vegetation patterns. The direct impact of flooding on vegetation is reflected in altitudinally related patterns in vegetation across the riparian and floodplain zones. For example, Bren (1988a, b) and Bren & Gibbs (1986) identify relationships between flood levels and frequency, and the vegetation associations within a riparian red gum (*Eucalyptus camaldulensis*) forest. Such clear relationships between vegetation character and flood frequency have been used in some studies to define limits of floods of different frequency (e.g. Bedinger, 1978; Hupp, 1987).

In addition to the direct influence of inundation frequency, sediment transfer processes during floods have major impacts on vegetation close to the river system through direct abrasion, deposition and scour of sediment. In these environments, the survival of trees depends on their ability to survive hydraulic–abrasive damage from flow velocities and transported sediment or their ability to develop root systems to keep pace with sedimentation. Sigafoos (1964) and Sigafoos & Sigafoos (1966) describe the use of evidence from flood-damaged trees (including scar tissue, sprouting from damaged branches and trunks and the development of adventitious root systems in response to sedimentation) to reconstruct the flooding and sedimentation history of the floodplain of the Potomac River. Hupp & Morris (1990) combined analyses of tree age, species composition and adventitious root development to explore sedimentation patterns and rates in the Black Swamp along the Cache River, Arkansas. Furthermore, Hupp (1987, 1988) combined evidence of flood damage and sedimentation rates reconstructed from riparian trees with information on vegetation species composition and floodplain–channel morphological components to extend flood frequency records.

FLOODPLAIN ZONES

The integrated impact of hydrological and fluvial geomorphological processes on the character of riparian forests in the high energy, confined environment of headwater rivers and their floodplains is well illustrated by the research of C.R. Hupp. Working mainly in Virginia, he has investigated interactions between processes of hillslope drainage, river flood frequency and fluvial sediment transfer, and the characteristics of riparian woodland vegetation. For example, cross-valley and down-valley sequences of fluvial landforms have been identified which support distinct vegetation communities along N. Virginian rivers (Hupp, 1982, 1983, 1986, 1990; Osterkamp & Hupp, 1984). Valley–floodplain cross sections include the channel bed (under water at mean discharge), channel depositional bars (at the level of about 40% flow duration) which support herbaceous plants, the channel shelf (at approximately 5–25% flow duration) covered by riparian shrubs, the floodplain (1–3 years flood frequency) supporting floodplain forest, and terraces (representing former floodplains) with terrace forest assemblages. In the upstream direction, the channel shelf with its distinctive vegetation persists well beyond the upstream limits of the floodplain.

Fetherston, Naiman & Bilby (1995), also stress the association between physical processes and riparian forest development in montane river networks of the Pacific Northwest. They note that 'the diverse vegetation supported by riparian landscapes ... is the product of ... disturbance events interacting with spatially heterogeneous environmental conditions' (Fetherston *et al.*, 1995, p. 134).

Further downstream, in the more extensive floodplains of higher-order, lower-energy rivers, a broad zonation in floodplain vegetation frequently becomes more marked, reflecting the transition from hydraulically-dominated to hydrologically-dominated vegetation types along transects from the river to the adjacent hillslopes. Thus, Pautou & Décamps (1985) and Décamps & Tabacchi (1994) describe three altitudinal belts on the Rhone, Garonne and Ardour

floodplains: a lower belt of pioneer communities on recently deposited alluvium: an intermediate belt of softwood communities on areas flooded during high flows; and an upper belt of hardwoods on more elevated areas. These three zones represent the varying altitudinal influence of the flood disturbance regime on the riparian communities. Similar patterns and processes have also been recognized on forested floodplains in tropical latitudes (e.g. Parodi & Freitas, 1990); within the shrub communities of high latitude floodplains (e.g. van Hees, 1990); and within alluvial scrub environments in hot arid zones (e.g. Hanes, Friesen & Keane, 1989), where the joint influence of groundwater hydrology and flash-flooding provides particularly strong hydrological and hydraulic gradients.

CHANNEL PLANFORM CHANGE

In addition to the broad zonation in floodplain vegetation in response to flood disturbance, local variations in fluvial geomorphological processes lead to the development of a mosaic of disturbance patches at a finer spatial scale, which are often associated with characteristic vegetation species and communities.

Patterns within the vegetation mosaic can help to identify the mode of formation of sections of floodplain, differentiating for example, between floodplains built predominantly by lateral river migration, by occupation and abandonment of more randomly distributed channel locations, or by vertical accretion.

The level of interaction between floodplain forests and river systems depends to a large extent upon the size of trees in comparison with the size of the main threads of the river system. For example, on very large river systems the trees have little direct impact on fluvial processes, but the pattern in the riparian forest may reflect the range of physical conditions left by past fluvial processes. Thus, Page & Nanson (1982) illustrate differences in forest texture induced by lateral migration of the Fort Nelson River, British Columbia, and the building of a scrolled floodplain. Similarly, Lamotte (1990) identifies typical vegetation successions on ridges and in swales within the floodplains of a part of Peruvian Amazonia. The resultant pattern in the forest cover reflects the sequence of scroll bars left by the migration of the river in developing its scrolled floodplain. Where channel migration occurs, the development of marginal bars exposes fresh areas for vegetation colonization. Vegetation succession on these new landforms can help to reveal the age of particular features and their past and present environmental characteristics. For example, Everitt (1968) used the age of cottonwood trees to reconstruct the history of channel migration on a section of the floodplain of the Little Missouri River; Bellah & Hulbert (1974) used the composition of vegetation on the Republican River floodplain as an index of the age of geomorphic features; and McBride & Strahan (1984) described the interaction between vegetation colonization and succession in the development and stabilization of point bars along Dry Creek, California.

Hickin (1984) emphasized that although vegetation may have little influence on where bars develop, it may have a significant influence on their growth through a filtering and sheltering action on deposited sediment. Stretches of Ozark streams with drainage areas greater than 100–200 km^2 (McKenney, Jacobson & Wertheimer, 1995) have been found to represent a transition environment where vegetation can have a direct impact on channel planform change in specific circumstances. McKenny *et al.* (1995) differentiate between low-gradient (low energy) and high-gradient (high energy) river stretches. The former are characterized by unidirectional channel migration and bar deposition, where the bars exhibit prominent bands of woody vegetation which provide depositional sites during bedload-transporting events. The latter stretches are dominated by channel avulsion, where woody vegetation has a more direct impact on channel planform change by creating areas of erosional resistance that become temporary islands.

On braided and anastomosing rivers, channel planform change often results from channel abandonment (e.g. Brown, this issue). The mode and rate of abandonment impacts on local hydrological conditions and on the calibre and rate of sedimentation in the abandoned sections. The pattern of vegetation on such floodplains can be indicative of the sequence and the nature of channel development and abandonment (Kalliola & Puhakka, 1988; Petts *et al.*, 1992).

BANK MORPHOLOGY

At a local scale, woody riparian vegetation has a direct impact on river bank stability through its influence on marginal flow velocities and sedimentation, through the impact of roots on bank sediment tensile strength, and through improved bank drainage via root-induced

macropores (Thorne, 1990). A model of bank recovery after channelization in Tennessee rivers (Simon & Hupp, 1987; Hupp, 1992) is associated with distinctive woody vegetation establishment patterns which illustrates that the composition of vegetation on river banks may be indicative of their stability and stage of evolution. After initial severe mass movement, pioneer species including black willow (*Salix nigra*), river birch (*Betula nigra*), boxelder (*Acer negundo*), silver maple (*Acer saccharinum*), and cottonwood (*Populus deltoides*), establish low on the banks in the middle stages of bank recovery. This establishment leads to an interaction between vegetation growth and deposition of sediments, resulting in a reduction of the bank slope. A second group of more 'stable site' species e.g. ironwood (*Carpinus caroliniana*), green ash (*Fraxinus pennsylvanica*), sweet gum (*Liquidambar styraciflua*), American elm (*Ulmus americana*), bald cypress (*Taxodium distichum*), and tupelo gum (*Nyssa aquatica*), then establish. After bank recovery is complete, a final suite of bottomland oaks establishes.

Other properties of bank vegetation can indicate the significance of geomorphological processes. For example, Gregory (1992) describes the way in which tree root exposure, the position of trees on river banks and the presence of bent trunks can be used to identify eroding banks. In contrast, Nolan & Janda (1979) illustrate how channel aggradation and an associated rise in the bank water table may be reflected in the vigour of riparian trees.

WOODY DEBRIS

A particular characteristic of woodland river channels is the influence of large woody debris (LWD) (Maser & Sedell, 1994; Gurnell, Gregory & Petts, 1995). It is delivered naturally to the river system through a variety of processes (Keller & Swanson, 1979) and forms a very important component of the roughness or flow resistance of the channel system. The interaction between input and output processes for debris and river channels of different size leads to characteristic distributions of large wood in undisturbed river systems. LWD directly impinges upon the dissipation of stream energy, leading to influences on the hydrology (MacDonald, Keller & Tally, 1982) and hydraulics (Ehrman & Lamberti, 1992) of in-channel flows and the distribution of overbank flows (Hickin, 1984), and thus on the transport and storage of sediments and organic material within the river channel system and on the floodplain (Keller & Swanson, 1979; Keller & Tally, 1979; Lisle, 1981; Hedin, Mayer & Likens, 1988). Comparative studies between streams where debris has been retained or removed suggests that sediment yield can increase by an order of magnitude when LWD is cleared, indicating the important sediment storage effect of the wood.

Influences on flow hydraulics and sediment storage and transport lead to secondary impacts on the geomorphology of woodland river channels including: the average condition and variance in channel dimensions (Keller & Swanson, 1979; Hogan, 1986; Nakamura & Swanson, 1993); the magnitude and distribution of pools and riffles (Bisson *et al.*, 1982, 1987; Andrus, Long & Froehlich, 1988; Robison & Beschta, 1990); and the overall stability and pattern of river channels (Bilby, 1984; Heede, 1985). Channel pattern is controlled by: bank stabilization by tree roots and marginal debris leading to a reduced ability for the channel to migrate; by the reduced sediment transport giving the flow enhanced erosive power; and, in low to medium order channels, by locally enhanced overbank flows at woody debris dam sites, resulting in the cutting of new channels and the abandonment of old ones.

CONCLUSIONS

The dependent relationship between floodplain vegetation and hydrological and fluvial processes is well illustrated by a study of the River Ain, France, where anthropogenic influences have induced channel planform change from a braided to a single thread channel pattern (Marston *et al.*, 1995). Shortening of the river course and the construction of embankments has resulted in channel entrenchment, reduced floodplain disturbance and a lowering of floodplain water tables. The result is that pioneer and disturbance-dependent landscapes have reduced in area, being replaced by more homogeneous alluvial forest. The interaction between river and floodplain has been significantly reduced leading to a reduction in floodplain landscape diversity. Similar isolation of river from floodplain has been attributed simply to continued and thorough clearance of woody debris from the Willamette River, Oregon (Sedell & Froggatt, 1984). Petts *et al.* (1989) show how a variety of engineering works over the last 200 years have induced changes similar to those described above on large rivers throughout the mid-latitudes. Petts (1990) reviews the

environmental consequences of such changes and notes the 'largely cosmetic' conservation measures of the 1980s. 'Major objections to restoring riparian and floodplain woods relate to the possible negative impacts on flood control and to the uncertain hydrological and hydraulic consequences of alternatives to traditional channel designs' (Petts, 1990, p. 28). However, such 'negative' impacts on flood control can be interpreted to be positive if floodplain storage is seen as an integral component of designs for flood alleviation. This paper has shown that research is revealing the hydrological and hydraulic consequences of afforesting floodplains and is providing a basis for developing alternative channel designs which permit enhanced connectivity between river and floodplain. Furthermore, it has illustrated that if floodplain forests are to be retained or recreated (e.g. Peterken & Hughes, 1995), a hydrogeomorphologically active channel and floodplain environment is essential.

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Coarse Woody Debris in Riparian Zones

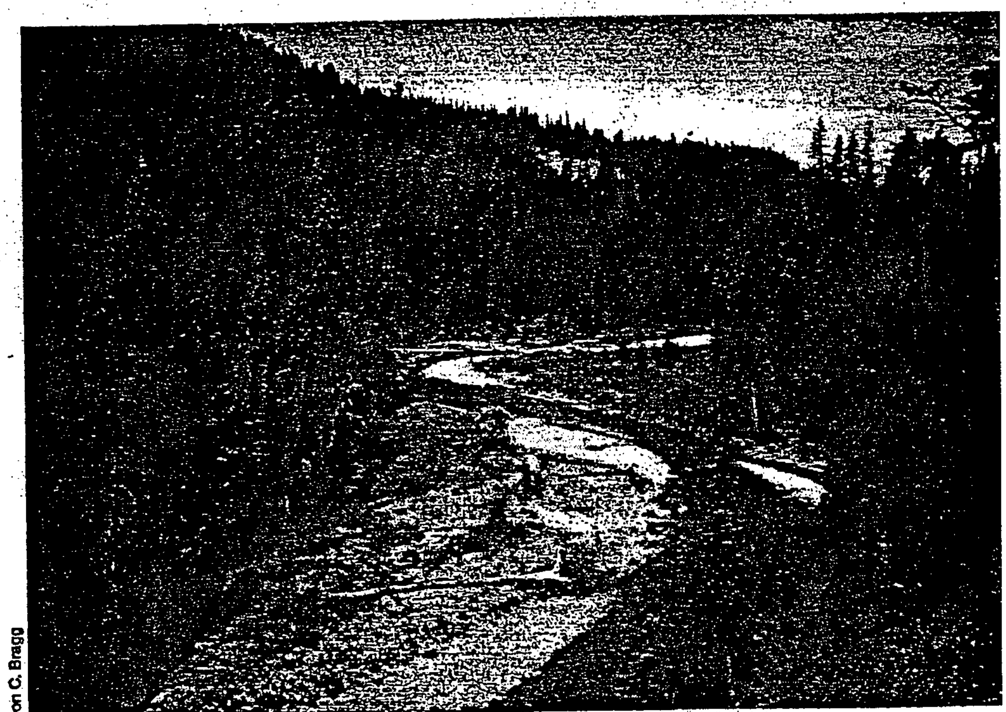
In managing coarse woody debris, foresters, fishery biologists, wildlife managers, geomorphologists, recreation specialists, and policy personnel have many opportunities to coordinate watershed planning, cooperatively utilize natural patterns and processes, and improve socioecological systems. Past (and even present) management of riparian debris has been inconsistent. But a growing body of biophysical evidence, coupled with growing acceptance of ecosystem management on public lands, gives hope that together we can sustain this vital component of ecosystem integrity.

By Don C. Bragg and Jeffrey L. Kershner

Interdisciplinary cooperation is necessary to ensure long-term sustainability of our nation's forests and restore the processes and functions associated with healthy ecosystems. Past models of forest management were often driven by narrow resource objectives and did not consider the variety of natural ecosystems. We believe that large-scale efforts, such as the Northwest Forest Plan (FEMAT 1993) and watershed analysis (Kershner 1997), provide new opportunities for cooperation among natural resource professionals. Prospects for interaction are considerable, since changes in forests have affected most of the riparian zones in North America.

Physical and Biological Functions

Riparian zones represent important ecotones in forested landscapes. They provide such critical ecosystem functions as wildlife nesting and rearing sites, habitat for rare plants, mediation of stream temperatures, and the growth of trees with subsequent production of large dead wood (also called coarse woody debris, frequently abbreviated CWD). This debris includes whole dead trees with attached root wads, sections of the bole, and large



Don C. Bragg

Professionals of many disciplines should consider riparian debris in multiple spatial and temporal contexts to integrate biophysical necessities with socioeconomic realities. *Right:* Human influences on riparian zones have long shaped stream characteristics. Even treatments done early this century (like removing woody debris and other obstructions to float railroad ties) have environmental legacies lasting to this day.

Opportunity for Interdisciplinary Interaction

branches. Interpretations of debris have varied by forest type, site potential, and geographic location, but its significance has become clearer in recent decades (Harmon et al. 1986; Bisson et al. 1987).

Studies have associated coarse woody debris with the quality and productivity of riparian habitat (Harmon et al. 1986; Murphy et al. 1986; Hartman et al. 1987; Maser and Sedell 1994), with stream geomorphology and channel stability (Swanson et al. 1982; Harmon et al. 1986; Bisson et al. 1987), with biogeochemical dynamics (Vannote et al. 1980; Bisson et al. 1987), and as an indicator of intact old-growth forests (Sedell et al. 1985). The primary source of woody debris in streams and lakes is the adjacent riparian zone (Harmon et al. 1986; McDade et al. 1990; Gregory et al. 1991). Debris may also originate in upslope forests and move to streams via landslides, debris torrents, and avalanches (Harmon et al. 1986; Bisson et al. 1987).

The effects of debris on riparian structure change with stream size. Along small streams, downed trees may span the entire channel, causing debris to accumulate in jams that can partially or completely block the flow. This blockage may divert the path of the stream, resulting in localized flooding, erosion, tree mortality, and new habitat. In addition to directly contributing structure, natural obstacles also capture other pieces of debris moving downstream, building large aggregations (Harmon et al. 1986). Debris jams retain sediment and then release this material more slowly during stormflows (Gregory et al. 1991). Streams also move debris into various positions within the channel and may scour or deposit sediments, depending on the configuration of the debris and the flow patterns around the obstruction. This scour-and-fill cycle creates a complex array of features, including extensive pools and riffles within the active channel (Gregory et al. 1991; Maser and Sedell 1994). Smaller headwater streams may be important sources of debris for larger streams, which may develop considerable accumulations of debris in the floodplain. When high flows inundate the floodplain, debris jams normally outside the active channel provide important refugia for many organisms.

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Before the 1970s, many believed that riparian debris should be removed to facilitate fish migration and limit flood hazards. This attitude predominated in the northwestern United States, though debris extraction was also widely practiced throughout the rest of the country (Sedell and Luchessa 1982). During the late 1960s and early 1970s, biologists began reexamining the role of woody debris in streams. Riparian debris is important to juvenile salmon, steelhead, trout, and other species in western North America (Bisson et al. 1987; Hartman et al. 1987; Young et al. 1994) because it creates slow-velocity resting areas and important hiding cover (Angermeier and Karr 1984).

Coarse woody debris is also a significant habitat in warm-water streams in the central and southern United States and tropical regions (Angermeier and Karr 1984; Wallace and Benke 1984). Cranes, herons, kingfishers, dippers, otters, mink, snakes, and salamanders are among the animals that use stream- and lake-associated debris for hunting and resting. Downed debris serves as an important substrate for a host of riparian species, such as lichens, mosses, fungi, ferns and fern allies, devil's club, spruces, hemlocks, and cedars. Decomposed or fragmented debris contributes to aquatic coarse-particulate organic matter, which in turn supports bacteria, fungi, and invertebrates (and correspondingly higher trophic levels).

The nutrients released from woody debris then become available to associated environments (Vannote et al. 1980; Gregory et al. 1991). Debris fulfills similar biophysical roles in pond, lake, and estuarine systems.

The Impact of Forestry

Perhaps no other anthropogenic factor has had greater long-term influence on the recruitment and retention of riparian debris than timber harvesting and transport. Loggers have used streams across North America to float harvested timber to sawmills. The images are romantic, but running rafts of logs down cascading water resulted in significant damage to those stream systems. Obstructions caused large, dangerous jams, and so rocks, stumps, and downed logs were removed before the drives. Although it reduced the likelihood of logjams and thus minimized the risks to the lumberjacks, this practice had unanticipated long-term consequences on channel complexity. For example, some stream systems in the western United States have yet to recover historic levels of coarse woody debris decades after clearing for railroad-tie drives (Young et al. 1994; Kershner 1997).

In many areas, riparian debris was a resource to be exploited. Especially in the Pacific Northwest, large, slowly decaying logs were taken from stream channels and milled into lumber or dried and burned as fuel (Maser and Sedell 1994). A relatively new concern in riparian zones is salvaging of firewood, with people stripping some areas of debris almost as quickly as it forms. These areas are favored targets because they are usually easily accessible and often act as collection points for woody debris. It is not yet a widespread problem, but a number of watersheds are suffering from depleted wood-based habitats because of this practice. Stream channels have also served as repositories for logging slash, although the instability caused by this action was recognized early and discouraged by Froehlich (1973). The removal of riparian slash has led to problems, however. Since it could be difficult and time-consuming to distinguish logging slash from natural debris, many loggers simply removed all dead wood within the channel, destroying natural accumulations of debris (Froehlich 1973; Murphy et al. 1986).

Perhaps the most pervasive influence of forestry practices on riparian debris operates on a larger spatiotemporal scale and is much less obvious. The conversion of millions of acres of decaying old-growth forest into relatively vigorous, second-growth stands has greatly reduced the recruitment of large, dead trees and replaced them with smaller, less substantial pieces of debris (McDade et al. 1990; Kershner 1997). Extensive forest management has also altered natural disturbance regimes. Although some events (such as landslides and introduced pathogens) have increased in frequency since we began manipulating our forests, others have been notably suppressed. Forest fires, for example, periodically affected extensive areas (Romme 1982), providing for episodic delivery of riparian debris and considerable variability in recruitment patterns (Bragg 1997; also see Rieman and Clayton 1997). Controlling natural catastrophes may reduce the inherent variation of affected systems, and some suggest this could lead to decreased ecosystem stability (Holling and Meffe 1996).

Fortunately, we can now anticipate the effects of forest management on riparian debris. Several simulation models (Rainville et al. 1985; Murphy and Koski 1989; McDade et al. 1990; Van Sickle and Gregory 1990; Bragg and Kershner 1997) have predicted the behavior of riparian debris under undisturbed conditions and in response to management practices. More challenging (but not impossible) will be assessing changes to natural disturbance regimes and the effects of these differences on the long-term and large-scale pattern and process of riparian debris (Froehlich 1973; Murphy and Koski 1989; Bragg 1997).

Evolution of Management

As we learn more about the role of coarse woody debris in riparian systems, our approach toward its management also evolves. In most areas, riparian debris is no longer considered an obstacle to be removed or an untapped fiber resource; it is a critical element in ecosystem functionality. We have yet to develop a consistent management strategy

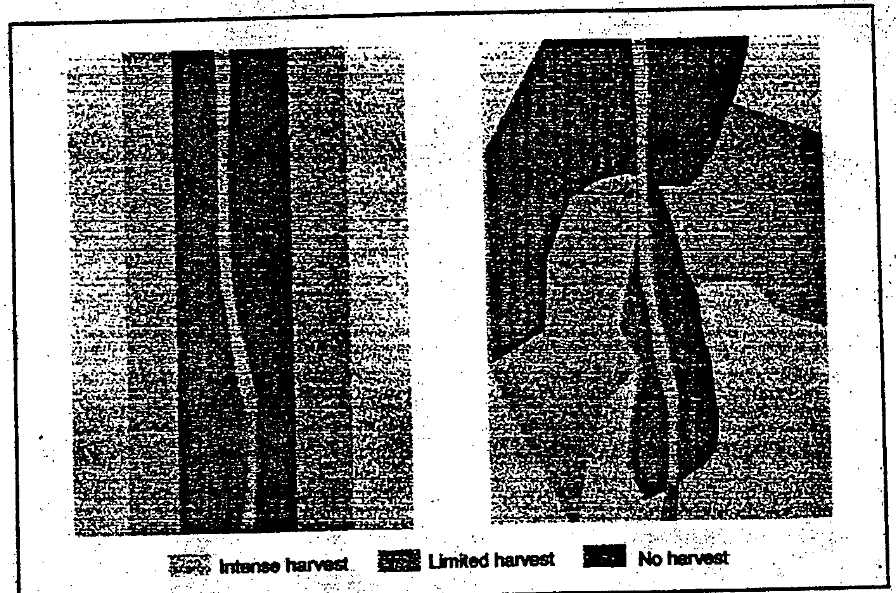

Figure 1. **Possible patterns for riparian management areas that incorporate both timber production and nonforestry interests. Zones of different harvest intensity (including a no-entrance region) could be used *(left)*. A more patchy distribution of treatments *(right)* results in a variety of different successional stages along the channel. The former is probably much simpler to implement in the field, but the alternative strategy would better mimic natural forest patterns (a cornerstone of ecosystem management).**

rooted in good science and policy, however. Great opportunities for interdisciplinary cooperation lie in deciding how much debris is sufficient at what scale, how we get there from here, and how we maintain this level once we reach it. Participating disciplines may have different perspectives on how to achieve these goals, but the goals are not necessarily mutually exclusive. For example, abundant debris contributes to channel stability by preserving both fish habitat and sediment retention without additional effort or expense. Another challenge for managers lies in the uniqueness of each riparian system from both an ecological and a sociological perspective. This makes it difficult to develop universal approaches for managing riparian debris.

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Historically, riparian debris management has focused on the small-scale effects debris has on active stream channels, as either an obstruction to commerce or a provider of habitat.

Riparian forest buffer strips were the first (and probably the simplest) way to address debris dynamics. However, wide buffers reduce the amount of forest available for logging (Bren 1995), and narrow strips are vulnerable to accelerated windthrow and may not provide other desired attributes, such as stream shading or forest interior microclimate. Since most riparian debris comes from trees in the immediate vicinity of the channel, buffers need to be only 50 to 200 feet wide under most conditions to ensure continuing debris recruitment. Buffer zones could also be less extensive for small or ephemeral headwater streams, since materials deposited along these reaches rarely move downstream, thus limiting their overall contribution to debris. Although this strategy may satisfy production-oriented foresters, fisheries or wildlife managers may balk at narrow reserve areas because of the effects on other riparian features.

Streamside timber management affects more than just debris recruitment. Changes to flow patterns, sedimentation, biogeochemistry, and microclimate often coincide with this type of event. The term *buffers* also implies that these zones are excluded from cutting. Delineating such regions could prove ecologically, silviculturally, and administratively challenging (*fig. 1*). A gradation in harvest intensity along relatively broad riparian management areas should address most concerns. A simplified example of this strategy could include a 50- to 100-foot-wide no-entrance zone, followed by additional areas of increasing levels of harvest. Another alternative would involve patches of intensive harvest along the edge of the channel, to introduce some environmental variability to the riparian zone, with other reaches having wider-than-usual undisturbed or lightly harvested areas. Determining the size, shape, and spatial configuration of any riparian treatment should depend on both the local environment's response to the manipulation and the desired result. To avoid disruptions that may take years to rectify, managers need to consider overall ecosystem objectives before trying to match current riparian zone conditions with presumed natural landscape patterns.

Although difficult, identification of historic debris levels would help resource managers in areas from forestry to fisheries to geomorphology. Perhaps the best way to interpret historical levels is over large spatial scales, so that watersheds

Collaborative Management

Actually practicing ecosystem management can be difficult for many field workers because of the challenge of identifying opportunities for interaction. We propose riparian debris as a venue for the collaboration because it either directly or indirectly reflects all the features in this thorough definition of ecosystem management (Endter-Wada et al. 1998, p. 891):

"Ecosystem management ... focus[es] on ecological systems that may cross administrative and political boundaries, incorporat[es] a systems perspective sensitive to scale, and manag[es] for ecological diversity ... [an] evolving definition ... [including] ... the sustainability of human as well as ecological communities, ... adaptive management, and ... broad-based involvement and collaboration in implementing [it]."

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Debris becomes a link between terrestrial and riparian ecosystems. What affects one system can affect another.

(rather than specific reaches) define the range of debris variation. Inevitably, some areas are more conducive to debris recruitment or retention than others, so it is within these areas that intensive debris management should occur. This would benefit forestry interests by identifying areas that are more (or less) sensitive to riparian forest harvest. In determining which reaches will be most favorable for long-term (or large-scale) debris recruitment, fishery experts could emphasize those locations for habitat. Geomorphologists and hydrologists may approach watersheds from historical sediment and water-storage perspectives and therefore have an interest in their natural ranges of variation, which riparian debris strongly influences.

Social scientists could help interpret the biophysical importance of coarse woody debris to encourage appreciation for its function while alienating neither the public nor resource managers. This requires the fruitful inclusion of socioeconomic concerns early in ecosystem management planning and implementation, rather than as an afterthought (Endter-Wada et al. 1998). For example, resource managers, especially fishery biologists, have advocated more extensive protection of floodplains and their associated management areas. A growing but largely unrecognized threat to their stability is local communities' removal of dead trees for firewood. Although the negative impacts of salvaging debris in riparian zones may be obvious to the fishery biologist, efforts to convince the public of this problem have been less successful. After all, in some cases, generations have collected firewood in this manner, and it never seemed harmful before. Shifting to less sensitive upland regions and dispersing collection efforts should limit the damage. Changing people's attitudes will probably require making concerted efforts to inform residents about the pitfalls of removing firewood from riparian zones. Encouraging people to feel part of the solution, rather than the victims of yet another regulatory mandate, could help resolve this and other conflicts between citizens and resource agencies.

Forest practices can also assist in restoring streams that have not yet recovered from channel debris cleaning in the past (Young et al. 1994; Kershner 1997). The addition of large debris would benefit stream habitat quality, but in many instances the adjacent riparian forests have not matured sufficiently to consistently contribute large dead trees. Large debris is of particular value because it provides the most stable structure, which contributes the most to pool formation, fish habitat, sediment storage, and other biological legacies (Harmon et al. 1986; Bilby and Ward 1991). In such areas, the benefits of supplementing natural debris by felling otherwise healthy trees into the channel may be considerable. Once again, resource professionals need to make a cooperative effort to explain to concerned citizens why big trees are being killed next to their favorite trout stream. Simply listing the benefits of this strategy may prove inadequate, however. Development of demonstration sites and involvement of local resource users (fishing or hunting clubs, birdwatchers, Scouts, environmental groups) at the early stages should help minimize conflicts.

Professionals of many disciplines should consult to evaluate the management approach best suited to a particular stream. From a policy standpoint, maintaining riparian debris and ensuring its continued recruitment contribute to multiple use in this biota-, structure-, and process-rich environment. A geomorphologist may caution against harvesting along streams with unstable, steep, or vulnerable slopes that could fail after harvest, or predict that changes to drainage patterns will increase the likelihood of channel-scouring debris flows or downstream floods. A fishery biologist may seek to improve overall stream productivity by opening stretches of canopy in regions with limited light, thereby increasing the levels of periphyton and, theoretically, other trophic levels. In areas where stream insolation is not an issue, preserving riparian zone temperature regimes may be important, thereby favoring retention of adjacent forests. Quality fish habitat almost invariably draws anglers, so from a recreation spe-

cialist's perspective, direct benefits come from creating habitat features by adding debris. Woody debris in streams can also enhance forest aesthetics for hikers, birdwatchers, and other nonconsumptive users.

The appeal of riparian debris may not be universal, however. Dead wood may prove an obstacle to boaters, a source of snags for anglers, and a physical impediment to hikers. Some may find tangles of dead trees unsightly; in other cases the benefits of debris (such as improved fish habitat) may attract so many users that the quality of the experience declines. As resource professionals, we need to balance our social preferences, which may differ widely from person to person, with the ecological realities required for robust ecosystems.

We also need to recognize that the socioeconomic structures, constraints, and interests we serve contribute to the successful management of a resource like riparian debris. The interchange between managers and the public is a two-way street. As with any other management issue, we cannot effectively separate our demands on riparian resources from ecological and political realities. The development of clear objectives among resource managers requires cooperative and even aggressive efforts to ensure our goals are accomplished.

Interdisciplinary Cooperation

Gone are the days when resource managers operated in isolation. In recent decades we have recognized the biophysical links between many natural systems. Society has also insisted that we retain the functionality of the environment, especially on public lands. The shift toward an ecosystem-based management model necessitates the interaction of professionals in many disciplines.

Although we have documented some of the negative impacts of poor debris management, we have also learned much from past practices. Now we can anticipate the response of watersheds to our manipulations. Riparian debris affects stream structure and function, fish and wildlife habitat, recreation opportunities, and other human activities while responding strongly to forest practices. It is therefore inadvisable to consider these factors separately when managing this resource. Identifying opportunities for interdisciplinary action first, rather than mitigating the damage after the fact, will contribute much to effective ecosystem management.

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Don C. Bragg (e-mail: SLSLJ@cc.usu.edu) is graduate research assistant, Department of Forest Resources and Ecology Center, Utah State University, Logan, UT 84322-5215; Jeffrey L. Kershner is fish ecologist, Fish Ecology Unit, USDA Forest Service, Department of Fisheries and Wildlife, Utah State University, Logan.

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6 Medium–Low-Gradient Streams of the Gulf Coastal Plain

JAMES D. FELLEY

Department of Biological and Environmental Sciences, McNeese State University, Lake Charles, LA 70609

PHYSICAL ENVIRONMENT

Geology

The geology traversed by the streams covered in this chapter is of relatively recent origin (Thornbury 1965). Medium-low gradient streams of the Gulf coastal plain primarily flow through Tertiary formations identified by Thornbury. These portions of the Gulf coastal plain were largely formed during the Oligocene. Large amounts of water, now locked up as ice, were then in liquid form (Vail and Hardenbol 1979), and oceans intruded almost to the fall line (a demarcation between the metamorphosed geologic regions of the interior—the present-day Piedmont—and sediments deposited by Cretaceous seas). When the Oligocene oceans retreated, they left behind the relatively flat expanses of clayey and sandy soils that now comprise most of the coastal plains. Murray (1961) has presented a compendium of coastal plain environments in North America. Riggs (1984) discusses post-Oligocene sea-level changes and their geological effects. Summaries of the geology of the region may also be found in Swift et al. (1986) and Conner and Suttkus (1986). Other than clays and sands deposited during the Oligocene, special geological features of the Gulf coastal plain include deposits of loess in western Mississippi, and uplifted coralline beds in peninsular Florida and in portions of the Florida panhandle (Bernard and LeBlanc 1965).

Subsequent changes in sea level have left their mark (Vail and Hardenbol 1979). Evidence of Pleistocene sea level changes can be found in some areas (Cooke 1939, Flint 1957, MacNeil 1949). At least three sets of Pleistocene terraces in Louisiana mark sea-level changes (Saucier and Fleetwood 1970).

James D. Felley's present address is the Office of Information Resource Management, Room 2310 A&I Building, Smithsonian Institution, 900 Jefferson Dr., S.W., Washington, DC 20560.

On the Florida peninsula, soils associated with contours less than 30 m are likely of marine Pleistocene origin. Opdyke et al. (1984) demonstrated that dissolution of limestone bedrock of the area has caused epeirogenic uplift of more than 30 m. Other soils of the Gulf coastal plain may be of Eolian origin (e.g., loess soils of Mississippi) (Flint 1957, Snowdon and Priddy 1968).

Poorly consolidated soils of Pleistocene or Pliocene origin were easily eroded (Grissinger et al. 1982, Holland 1944), and now even headwater streams have relatively low gradients (though see Beck 1973). Most medium-low gradient streams of the Gulf coastal plain flow over sand or sand/clay substrates. A few streams have gravel bottoms (e.g., Bayou Pierre in Mississippi) and at elevations less than 10 m, many streams in Louisiana have muddy bottoms. Streams in the Ochlockonee and Aucilla drainages have eroded their beds down to basement limestone and many are partially subterranean (Sellards 1917). Exposed limestone may be seen in the Chipola river drainage. Many streams in Florida limestone areas are spring-fed (Rosenau et al. 1977). Streams of the Florida panhandle west of the Apalachicola continue to erode their beds in response to uplift of the coastal plain in the region (Price and Whetstone 1977).

Climate

The Gulf coastal plain is affected by two general types of rainfall patterns: Weather fronts passing through in winter and spring bring most of the year's rain; in summer and fall, these fronts do not reach as far south as the coastal plain. In summer and fall, southerly winds bring rainfall in the form of thermal thundershowers [50–70 inches per year over a particular area (Geraghty et al. 1973)]. Hurricanes are unpredictable but important sources of rainfall in late summer and fall. Muller (1977) provided a detailed summary of weather patterns that affect the Gulf coastal area. Runoff tends to be highest in winter and spring, when rainfall is highest and temperature and evapotranspiration are lowest. Conversely, runoff is lowest in summer and fall (Geraghty et al. 1973, Gosselink et al. 1979). In the Florida peninsula and parts of the Florida panhandle, frontal rain events are much less important, and summer and fall thundershowers account for most of the yearly rain (Fernald and Patton 1984). Fernald and Patton (1984) and Geraghty et al. (1973) show that stream flow in these regions tends to be highest in summer and fall.

Hydrology

The streams considered here are categorized as warmwater streams, which tend to have low gradients, moderate to high discharges, low turbulence, and rubble-sand-mud substrates (Winger 1981). Average discharge rates for selected streams of the Gulf coastal plain are listed in Table 1. Variation in flow among these streams is most closely tied to drainage area ($r = .923$, $p > .001$).

TABLE 1 Drainage Areas and Yearly Averages of Physicochemical Variables for Selected Stream Systems of the Gulf Coastal Plain

Drainage	Area (km^2)	Flow (m^3/s)	Temperature (°C)	Conductivity (µS/cm)	Dissolved Oxygen (mg/L)	pH	Hardness (mg/L)	Phosphate (mg/L)
Calcasieu[a]	4 403	71.1	19.0	184	7.6	6.8	17.2	.08
Amite[a]	133	1.5	20.0	181	8.5	6.2	12.9	.10
Tickfaw[a]	247	6.0	18.4	219	8.4	6.4	13.7	.11
Tangipahoa[a]	1 673	24.0	19.4	188	8.4	6.2	13.1	.15
Perdido[b]	2 396	21.8	19.7	22	8.4	4.7	3.6	.10
Escambia[b]	10 878	185.1	20.3	79	8.1	6.4	6.6	.13
Blackwater[b]	2 227	30.0	17.8	25	9.0	5.0	6.6	—
Yellow[b]	3 626	65.0	18.2	54	8.3	6.3	20.7	.08
Choctawhatchee[b]	12 033	204.8	20.8	98	7.5	6.6	37.9	.10
Ochlockonee[b]	5 957	45.7	19.8	121	7.5	6.1	25.8	.64
Aucilla[b]	2 279	15.7	19.4	116	7.3	5.9	55.2	.17
S. Withlacoochee[b]	5 180	32.0	22.4	264	5.4	7.6	125.4	.12
Hillsborough[b]	1 787	16.8	22.8	287	5.8	7.1	138.8	2.30
Peace[b]	5 957	32.7	22.2	316	7.8	6.9	117.6	8.30

[a]Data from STORET computer library, made available by Louisiana Department of Environment Quality.
[b]Data from Bass (1984).

There is strong seasonal variation in discharge within streams. Evapotranspiration and rainfall in the two seasons described above produce a period of low flow from June through October and a period of high flow from November through May (Felley and Felley 1987, Finger and Stewart 1987, Ross et al. 1987). Lowest flows are in August, September, and October; the highest flows are in January, February, and March, except in regions of Florida where summer thunderstorms are important contributors to total yearly rainfall (Beck 1973, Fernald and Patton 1984, Geraghty et al. 1973). Ross and Baker (1983) and Ross et al. (1987) presented discharge data over a period of years for tributaries of the Pascagoula River. Figure 1 illustrates the yearly flow regime of the Calcasieu River at a point where it is a sixth-order stream. Data for these streams show that differences between highest and lowest flows may be quite dramatic, high flows being up to 10 times greater than low flows.

Within streams, there is also much spatial variation in discharge-related variables. This variation is tied to stream order (Strahler 1957). Data collected by myself and S. M. Felley in 1984 showed that in headwater streams of the Calcasieu drainage (stream orders 1–2), flow (as measured by current speed), and variation in flow were greatest in the wet season; flow in these small, runoff-fed streams was negligible during the dry season (Fig. 2). Moore (1970) found that after high rainfall, temporary ponds may form in uppermost reaches of such small streams. By contrast, streams of orders 3–5 in the Calcasieu drainage had more spatial variation in current speeds in the dry season when

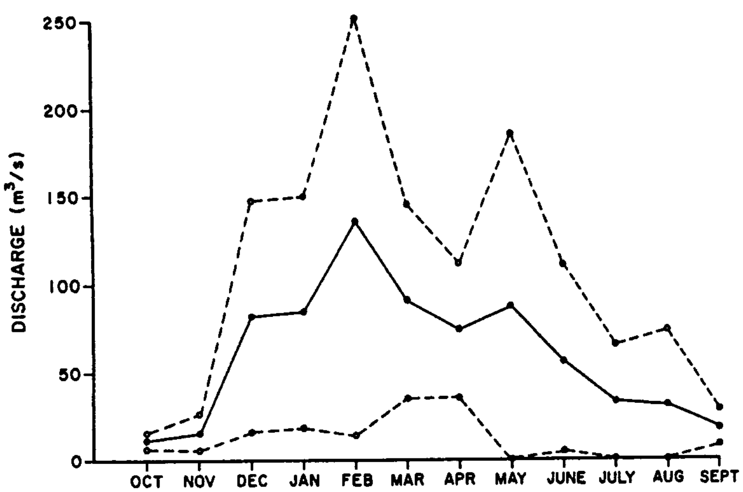

FIGURE 1. Average stream discharge by month for the Calcasieu River at Kinder, Louisiana (stream order 6). Raw data are monthly averages from 1975–1985 (U.S. Geological Survey stream gauging station). The solid line joins discharge means for the 10-year period; upper and lower dashed lines delimit one standard deviation.

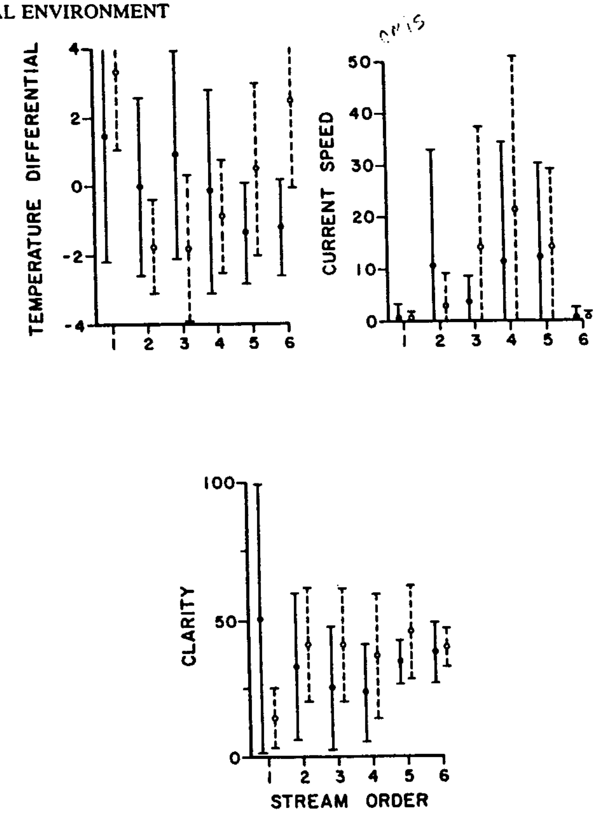

FIGURE 2. Means and one standard deviation of physical variables in streams of the Calcasieu drainage, Louisiana, by stream order. Solid lines and circles represent wet season (Dec–May) values; dashed lines and open circles represent dry season (June–Nov) values. Temperature differential (°C) is the difference between a location's temperature and the average drainage temperature in that season. Current speed was measured in cm/s, clarity as Secchi disk depth in cm. Sample sizes for particular stream orders (in the wet and dry season) were as follows: stream order 1 (7, 7); 2 (15, 7); 3 (14, 9); 4 (24, 21); 5 (8, 10); 6 (10, 7).

many of these reaches were characterized by pool–riffle sequences. In the wet season, high water obliterated pools and riffles, and flow was relatively constant. Variation in water temperature (Fig. 2) also followed a similar pattern: Upstream areas were most variable in the wet season, and downstream areas were most variable in the dry season.

Suspended load is related to discharge, and differs among streams (Beck 1965) due to erosion of different soil types and to different agricultural prac-

tices in these drainages. Within a stream system, there is also temporal and spatial variation in suspended load. Figure 2 illustrates variation in clarity in streams of different orders within the Calcasieu drainage. Table 2 illustrates the high variability of suspended load (turbidity) in five Louisiana streams during both wet and dry seasons. Most coefficients of variation were greater than 100%. These examples indicate that in Gulf coastal streams, suspended load is highest and most variable in the wet season (due to high and periodic rainfall and runoff).

Thus, spatial and temporal variability in hydrological variables is related to patterns of rainfall and evapotranspiration. In most systems, flow is low in late summer and fall, when upstream areas dry up or become pool–riffle sequences. Temperatures increase downstream. In the wet season, suspended load is high, temperatures are higher upstream (as a consequence of runoff), and pool–riffle sequences are obliterated by high water.

Chemicals

Streams of the Gulf coastal plain tend to be extremely low in dissolved substances, reflecting their watershed geochemistries (Shoup 1947). Averages for a number of streams in Florida and Louisiana (Table 1) demonstrate the low pH, conductivity, hardness, and nutrient levels of these streams. Exceptions are streams of the Florida peninsula that drain limestone deposits high in phosphate. These streams tend to have high levels of pH, dissolved substances, and nutrients. Oxygen levels in streams of the Gulf coastal plain tend to be relatively high, normally not dropping below 70% saturation all year long. Oxygen depletion may occur in low-order streams during low flow periods, in streams receiving municipal/industrial effluents, in the freshwater portions of tidal streams (Felley 1987), and in spring-fed streams (Rosenau et al. 1977). Data on physicochemistry may be found in Grady et al. (1983) for Bayou Sara, Louisiana; Beck (1973) for the Blackwater river system of Florida; and Bass and Cox (1985) for Florida streams.

Seasonal variation was apparent in water chemistry of Louisiana streams (Table 2). Conductivity and pH levels were lower in the wet season, higher in the dry season. Nitrate levels were higher during the wet season, presumably due to high runoff and low assimilation by primary producers during the cooler winter season. Lower nitrate levels during the dry season likely reflected high primary productivity that removed nitrates from the water column. By contrast, phosphate in these streams showed no seasonal variation and was found in low amounts. Levels of these two nutrients were highly variable in both seasons (Table 2).

Variation within streams of different orders in the Calcasieu drainage indicated that small streams (orders 1–3) were more variable in pH and oxygen saturation levels than larger streams in the same drainage. This variation was more pronounced in the dry season than in the wet season (Fig. 3). Conductivity was highly variable between Louisiana streams, but no pattern of spatial variation was evident within the Calcasieu river system (Fig. 3).

TABLE 2 Seasonal Means and Coefficients of Variation of Physicochemical Variables in Five Louisiana Rivers

River	Season	pH	Temperature	O_2 (%)	Turbidity	Conductivity	Nitrate	Phosphate
Calcasieu	Wet	6.4 (5.9)	12.8 (42.0)	75 (20.0)	26.5 (133.3)	78 (151.6)	.10 (100.0)	.05 (55.8)
	Dry	6.6 (6.8)	22.3 (19.1)	72 (15.9)	19.8 (61.7)	121 (151.4)	.10 (71.1)	.06 (90.6)
Amite	Wet	6.4 (7.6)	14.0 (40.0)	88 (15.0)	37.0 (163.3)	66 (139.0)	.23 (110.4)	.09 (81.1)
	Dry	6.6 (5.7)	22.4 (20.6)	88 (14.4)	13.1 (81.0)	65 (94.5)	.14 (59.0)	.07 (110.0)
Tickfaw	Wet	6.3 (9.9)	14.2 (38.5)	88 (17.4)	25.5 (70.5)	62 (90.6)	.30 (52.1)	.13 (85.8)
	Dry	6.6 (9.1)	23.0 (23.0)	88 (16.3)	13.5 (61.0)	72 (75.7)	.17 (58.4)	.09 (62.8)
Tangipahoa	Wet	6.5 (5.2)	15.8 (32.0)	97 (12.3)	32.4 (117.7)	67 (67.9)	.35 (30.8)	.13 (91.0)
	Dry	6.6 (4.9)	23.3 (18.6)	98 (13.2)	14.4 (195.3)	66 (38.9)	.29 (89.5)	.12 (144.4)
Tchefuncte	Wet	6.3 (7.7)	14.3 (36.9)	88 (15.0)	23.7 (175.6)	65 (102.2)	.31 (55.2)	.10 (53.8)
	Dry	6.4 (7.6)	21.6 (20.8)	88 (13.8)	22.7 (210.0)	79 (116.0)	.18 (62.2)	.10 (64.6)

Note. The wet season is from December through May, the dry season from June through November. Dissolved oxygen is expressed as percent saturation, turbidity in JTUs. Other units are as in Table 1.

Source. From the Louisiana Department of Water Quality records (1975–1985) (Louisiana Department of Environmental Quality, 1984).

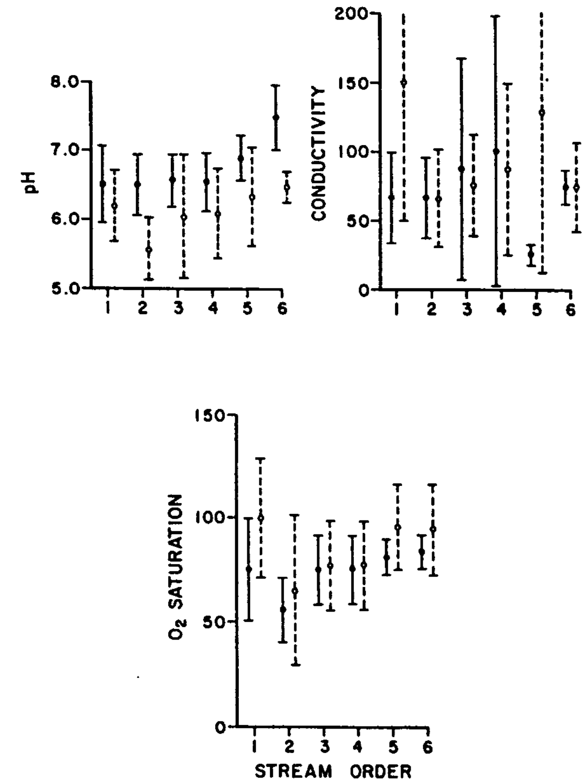

FIGURE 3. Means and one standard deviation of chemical variables in streams of the Calcasieu drainage, Louisiana, by stream order. Solid lines and circles represent wet season (Dec–May) values; dashed lines and open circles represents dry season (June–Nov) values. Conductivity was measured as μS/cm, oxygen saturation as a percentage. Sample sizes for stream orders (in the wet and dry seasons) were as follows: stream order 1 (7, 7); 2 (15, 7); 3 (14, 9); 4 (24, 21); 5 (8, 10); 6 (10, 7).

Drainages and Watershed Characteristics

There are recognized physicochemical differences among Gulf coastal drainages. Beck (1965) divided Florida waterways (including drainages covered here) into a number of categories, according to stream size and chemistry. Beck grouped the Florida streams covered in this chapter into the following categories: *sand-bottomed streams* (most of the streams considered here), *calcareous streams* (Aucilla, Peace, Hillsborough), and *larger rivers* (Escambia and Choctawhatchee). These streams are most easily divisible by their sizes and by their chemistries. Bass (1984) used Beck's (1965) scheme to characterize Florida waterways and gave drainage means for various physical and chemical variables. Bass and Cox (1985) discuss some other categorizations of Florida streams.

Beck's scheme does not adequately characterize streams of alluvial areas below 10 m elevation. These streams are often muddy-bottomed with banks lined by bald cypress (*Taxodium distichum*) and water tupelo (*Nyssa aquatica*). These trees form "living levees" which retard bank erosion. As a consequence, stream beds tend to be deep and steep-sided. Examples include the streams flowing into the downstream reaches of the Calcasieu river and estuary (Felley and Felley 1987, Felley 1987).

I identified patterns of environmental differences among drainages across the Gulf coastal plain, using principal components analysis. Data for this analysis were drainage means [from Bass (1984) for Florida streams; from Louisiana Department of Water Quality for five Louisiana streams]. Three separate locations in the Calcasieu drainage were also included.

A major trend differentiating Gulf-coastal streams relates to water chemistry (Fig. 4). The streams most differentiated from the others on principal component 1 were streams of the Florida peninsula that drain calcareous

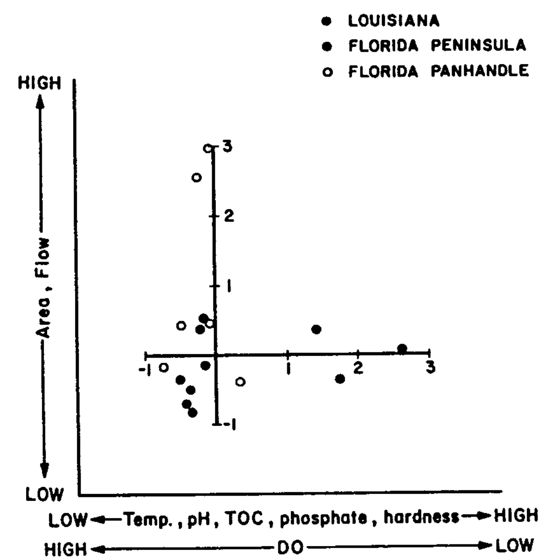

FIGURE 4. Plot of principal components of drainage means of physical and chemical variables. The *x* axis represents principal component 1 (relating to between-stream differences in temperature, pH, total organic carbon, phosphate and hardness). Principal component 2 (*y* axis) identifies drainage differences on the basis of drainage area and discharge.

deposits high in phosphates (Hillsborough, Peace, southern Withlacoochee). This division corresponds to a division between all other streams and the calcareous stream category of Beck (1965). Calcareous streams have high pH and high alkalinity, and tend to be quite productive. The other streams analyzed share similar chemical properties, being low in pH, dissolved solids, and so forth. Their chemical makeups are also quite similar to those of streams in the Atlantic coastal plain (Beck et al. 1974) (see Chapter 8).

Another trend differentiating streams of the Gulf coastal plain related to their drainage areas, and thus their average yearly flows. On principal component 2, the Escambia and Choctawhatchee systems are clearly separated (scores >2) from the others included in this study. In their downstream reaches, these two systems represent Beck's large rivers. Finally, smaller streams with low pH and dissolved solids represent Beck's sand-bottomed streams. These streams have scores between −1.0 and 1.0 on both principal components 1 and 2.

For much of the Gulf coastal plain, the typical stream seems to be a sand-bottomed stream. A few streams are markedly different on the basis of water chemistry or drainage size. There are some differences between the principal components results and Beck's (1965) classification. For example, Beck considered the southern Withlacoochee River to be a sand-bottomed stream, while Fig. 4 indicates that it is a calcareous stream. Despite minor differences such as this, a principal components analysis of stream means for environmental variables demonstrated that three of the stream-type categories identified by Beck can be used to classify the systems included in this analysis.

PLANT COMMUNITIES

Submergent Plants

Submergent plants are not much in evidence in most streams of the Gulf coastal plain, especially in upstream reaches. Much of the primary production that feeds these streams occurs in the riparian forests or swamp areas bordering the streams (see below). De la Cruz and Post (1977) found that gross primary production of a second order stream was from 4 to 28 g O_2/m^2 day^{-1}, which accounted for only one-fourth to one-half of the respiration in the stream. Primary production within the stream may be more important in downstream areas (Vannote et al. 1980).

Occurrence of submerged plants seems related to stream order. Moore (1970) found that temporary ponds (of the type found in headwaters) harbored large populations of *Eudorina* sp. (Volvocaceae), desmids (*Xanthidium* sp. and *Staurastrum* sp.), as well as *Spirogyra* sp. Organic detritus was thick in such pools. In the Calcasieu drainage, producers in low-order streams include algae and periphyton growing upon dead branches and snags in the water, as well as localized mats of diatoms in shallow, still areas (J. Felley personal observation). O'Quinn and Sullivan (1983) found encrusting diatoms to be an important community of primary producers in a small, calcareous Mississippi stream. Other unicellular producers have been found to be rare in running waters. In those environments covered in this chapter, Pecora (1973) found phytoflagellates only in canals, sloughs, and larger, slow-moving streams. Prescott (1942) noted that flowing waters of forested regions were poor habitats for algae. Table 3 lists dominant unicellular forms.

Table 3 also lists the vascular submerged species found in selected streams of the Gulf coastal plain. See Godfrey and Wooten (1979, 1981) for details of these species. Vegetated areas are not common in most of these streams, perhaps due to high variability in flow and turbidity, and to the presence of unstable sandy bottoms. In the Calcasieu drainage, vascular submergents tend to be abundant only in the lower reaches (stream orders 5–6) and in canals and oxbows. These are slow-flowing areas where clay or silt bottoms dominate. In southern Mississippi, *Sparganium americanum* may be common in some areas (S. T. Ross, personal communication). In Florida drainages surveyed by Bass and Hitt (1977, 1978) and Bass et al. (1979, 1980), vegetated areas were also sparse, accounting for only 5–6% of their benthic sample locations. In a small stream of the Calcasieu drainage, Carver (1975) found no submergent vascular plants at any of his benthic sampling locations. By contrast, sampling site descriptions from small tributaries of the Hillsborough and Peace rivers show that submergent vegetation may be quite dense in these drainages (Cowell and Carew 1976, Robertson and Piwowar 1985). In the environments found in Gulf coastal streams, primary producers may be mostly limited to substrates presented by snags, and to quiet water situations found in downstream areas, sloughs, and canals.

Emergent Plants

In the Gulf coastal plain, the important producers contributing to medium-low gradient streams are terrestrial plants surrounding headwaters (Gemborys and Hodgkins 1971, Finger and Stewart 1987), and plants growing in floodplains. Allochthonous inputs of fixed carbon from such communities have been studied by de la Cruz and Post (1977) and Post and de la Cruz (1977). Wharton et al. (1982) included an account of emergent plant communities of southeastern streams and floodplains, and Wooten (1986) examined edaphic features important to species of *Sagittaria*. In the Calcasieu drainage, some type of emergent vegetation was present at more than 30% of Felley and Felley's (1987) sampling locations. Table 3 lists important taxa found by various researchers. Godfrey and Wooten (1979, 1981) describe many of these species. Many species of emergent plants can grow or survive in flooded conditions as well as on saturated or drying soil. Thus, these plants are more resistant to the water level and flow fluctuations that characterize medium-low gradient streams of the Gulf coastal plain. Tree species such as bald cypress (*Taxodium distichum*) and water tupelo (*Nyssa aquatica*) grow along the edges of low gradient streams in areas which may be dry for only a short time each year, or only intermittently from year to year (Wharton et al. 1982). As mentioned above, these trees may stabilize the banks of such low-gradient streams.

TABLE 3 Dominant Macrophytes (Submergent and Emergent) and Unicellular Plants in Gulf Coastal Plain Streams

River System	Macrophytes		
	Submergent	Emergent	Unicellular forms
Calcasieu[1]	*Najas quadelupensis* (water nymph) *Ceratophyllum demersum* (coontail) *Cabomba caroliniana* (cabomba) *Utricularia vulgaris* (bladderwort)	*Taxodium distichum* (baldcypress) *Cladium jamaicense* (sawgrass) *Pontedoria cordata* (pickerelweed) *Alternanthera philoxeroides* (alligatorweed) *Brasenia schreberi* (watershield) *Nymphea odorata* (white water lily) *Cephalanthus occidentalis* (buttonbush) *Eichornia crassipes* (water hyacinth)	
Blackwater[2]	*Potamogeton* sp. (pondweed) *Vallisneria americana* (eelgrass) *Mayaca fluviatilis* (bogmoss) *Bacopa monnieri* (water hyssop) *Utricularia vulgaris* (bladderwort)	*Sagittaria* sp. (arrowhead) *Cladium jamaicense* (sawgrass) *Rynchospora* sp. (spike rush) *Orontium aquaticum* (golden club) *Xyris* sp. (yellow-eyed grass) *Pontedoria cordata* (pickerelweed) *Juncus repens* (rush) *Nuphar ulvacea* (black nuphar) *Nymphea* sp. (water lily) *Hypericum fasciculatum* (St. John's wort)	
Black Creek (MS)[3]		*Sparganium americanum* (burr-reed)	
Yellow River[4]	*Vallisneria* sp. (eelgrass)	*Typha* sp. (cattail) *Cladium jamaicense* (sawgrass)	
[redacted]			
		Hypericum americanum (St. John's wort) *Orontium* sp. (golden club) *Nuphar ulvacea* (black nuphar)	
Hilsborough,[5,6]	*Vallisneria neotropicalis* (eelgrass) *Potamogeton illinoiensis* (pondweed) *Egeria densa* (waterweed) *Hydrilla verticillata* (hydrilla) *Eichoria crassipes* (water hyacinth)		
Peace[7]	*Hydrochloa carolinensis* (hydrochloa)	*Sagittaria latifolia* (arrowhead)	
Small Creek in MS[8]			*Achnanthes minutissima* (diatom) *Cymbella turgida* (diatom) *Epithemia sorex* (diatom) *Gomphonema angustatum* (diatom)
Small Creek in MS[8]			*Navicula cryptocephala* (diatom) *N. menisculus* (diatom) *N. minima* (diatom) *Nitzschia dissipata* (diatom) *N. palea* (diatom)
Various LA drainages[9]			*Chlamydomonas pertusa* (phytoflagellate) *Euglena proxima* (phytoflagellate) *Trachelomonas gibberosa* (phytoflagellate)

References. 1, J. Felley (personal observation); 2, Bass and Hitt (1977); 3, Ross and Baker (1983); 4, Bass et al. (1979); 5, Cowell and Carew (1976); 6, Beck and Cowell (1976); 7, Robertson and Piwowar (1985); 8, O'Quinn and Sullivan (1983); 9, Pecora (1973).

ANIMAL COMMUNITIES

Invertebrates

The Gulf coastal plain is a region of high diversity for aquatic invertebrates, and biogeographic history accounts for much variation in invertebrate faunas among drainages of the Gulf coastal plain. Berner (1950) tabulated the distributions of mayfly genera in the southeastern United States, showing that the coastal plain has more genera than any other physiographic region of the southeastern United States. Beck (1980) discussed the biogeography of chironomids in the southeast. Barr and Chapin (1988) characterized Louisiana water beetles phylogenetically and biogeographically. Penn (1959) listed distributions and ecological characteristics of Louisiana crayfish species. Franz and Lee (1982) discussed the crayfishes found in underground streams of Florida's calcareous regions.

Within a stream system, invertebrate community characteristics change from headwater to downstream environments, as predicted by Vannote et al. (1980). Table 4 lists the dominant taxa in different habitats of small, medium-sized, and larger streams. In extreme headwaters, invertebrates are abundant in temporary ponds and include rotifers, copepods (primarily *Diaptomus* spp.), and cladocerans (primarily *Ceriodaphnia quadrangulata*) (Moore 1970). Larger arthropods are also found, including amphipods, isopods, odonates, and culicids. White (1985) discussed the invertebrate community of an intermittently flooded wetland area. The trophic base of these areas is mostly detritus.

In all habitats of permanent streams, oligochaetes and chironomids tend to be the dominant taxa (Bass and Hitt 1977, 1978, Bass et al. 1979, 1980, Carver 1975). Ephemeropterans, ceratopogonids and gastropods are also abundant. D. G. Bass, Jr. (personal communication) felt that stream invertebrate sampling techniques are biased against crayfish species, which may be important contributors to invertebrate biomass in these streams. The importance of other invertebrate taxa differs among habitats in medium-low gradient streams of the Gulf coastal plain.

In sand-bottomed streams (i.e., most upstream areas and small streams), riffle beetles (Elmidae) and trichopterans are abundant, and their importance decreases downstream. These forms are most often associated with snags and woody debris. Beck (1965) found that elmids were generally restricted to sand-bottomed streams. He also found that the ephemeropteran genus *Stenonema* and the trichopteran genus *Cheumatopsyche* were important in such streams. Peters and Jones (1973) described in some detail the invertebrate fauna of the Blackwater River, as well as the habitat preferences of particular species. They identified the nymphs of two mayflies (*Dolania americana* and *Homoeoneuria dolani*) as being specially adapted to living in the shifting substrates of sand-bottomed streams. The natural history of *D. americana* was further described by Peters and Peters (1977) and Tsui and Hubbard (1979). Berner (1950) gave ecological descriptions of various Florida ephemeropteran species. He found only nymphs of *Callibaetis floridanus* and *Caenis*

TABLE 4 Relative Abundances of Benthic Invertebrate Taxa in Various Stream Sizes and Habitats

		Stream Size			Bottom Type			
Taxon	Feeding Group	Large	Medium	Small	Sand	Sand/Litter	Mud/Litter	Vegetation
Oligochaeta	Substrate, debris feeding	+ + +	+ + +	+ + +	+ +	+ + +	+ + +	+ +
Isopoda	Scavenger, debris feeding	+ +	+			+	+ +	+ + +
Amphipoda	Omnivorous	+ +	+			+	+ +	+ +
Hydracarina	Piercer	+	+			+	+ +	+
Ephemeroptera	Collector–gatherer, scraper	+ +	+ +	+ +	+ +	+ +	+ +	+ + +
Anisoptera	Engulfer	+	+		+	+	+	+
Megaloptera	Engulfer	+	+		+	+	+	
Trichoptera	Shredder, collector–gatherer	+	+ +	+ +	+	+	+ +	+ +
Coleoptera (Elmidae)	Collector–gatherer, scraper	+	+	+ +	+	+	+ +	+
Chaoborinae	Piercer	+ +					+ +	
Chironomidae	Collector–gatherer, piercer	+ + +	+ + +	+ + +	+ + +	+ + +	+ + +	+ + +
Ceratopogonidae	Engulfer	+ +	+ +	+ +	+ +	+ +	+ +	+ +
Gastropoda	Scraper	+ +	+ +	+ +	+	+ +	+ +	+ +
Pelecypoda	Filterer	+ +	+ +		+ +	+ +	+ +	+ +

Note. + + +, abundant; + +, common; +, occasional.

Source. From data in Bass and Hitt (1977, 1978), Bass et al. (1979, 1980), and Carver (1975). Feeding groups are according to Merritt and Cummins (1978) and Pennak (1978).

diminuta in intermittent headwater streams. These two species were ubiquitous in the Florida drainages considered here, as were *Stenonema smithae* and *Hexagenia munda marilandica*. Mayfly nymphs characteristic of sand-bottomed streams with little vegetation included *Blasturus intermedius*, *Paraleptophlebia bradleyi*, and *Habrophlebiodes brunneipinnis*. Ephemeroptera characteristic of streams with vegetation were *Siphlopectron speciosum*, *Ephemerella trilineata*, *Acentrella ephippiata*, and *Baetis spinosus*.

Forms more characteristic of downstream reaches (Beck's larger rivers) include isopods, amphipods, phantom midge larvae (Chaoborinae), and pelecypods (Bass and Hitt 1978, Bass et al. 1980). Beck (1965) identified only the odonate genus *Argia* as restricted to larger rivers. Among the ephemeropterans, Berner (1950) found (in addition to the ubiquitous species listed above) *Stenonema exiguum* and *S. proximum* in larger rivers. Beck and Cowell (1976) reported on life history aspects of a freshwater shrimp (*Palaemonetes paludosus*) common in Florida rivers. The dominant pelecypod species of Florida streams was the introduced Asiatic *Corbicula* sp. (Bass and Hitt 1977, 1978, Bass et al. 1979, 1980). Beck (1965) found that the only taxa seemingly restricted to calcareous streams were the gastropod genera *Goniobasis* and *Campeloma*.

Average seasonal invertebrate biomass varies between drainages. Data in Bass and Hitt (1977, 1978) and Bass et al. (1979, 1980) showed differences in benthic invertebrate production of four Florida drainages (Escambia, Blackwater, Yellow, and Choctawhatchee). Averaged over all seasons and all habitat types, the Blackwater drainage produced 0.6 g/m^2, Escambia 3.4 g/m^2, Yellow 9.4 g/m^2, and Choctawhatchee 39.2 g/m^2 (wet weight in all cases).

There is also substantial variation in invertebrate productivity within each drainage, associated with different habitat types. The most productive habitats are those with vegetation or find sand/mud substrates with detritus (producing 50–60 g/m^2, wet weight). Benke et al. (1984) also found this in a blackwater river of the Atlantic coastal plain. These habitats have slow currents and a large trophic base (both detritus and primary producers). Thus, such habitats are open to invertebrate species lacking special adaptations to current, and to species from a variety of feeding groups (Merritt and Cummins 1978). Gregg and Rose (1982) showed that macrophytes interact with the environment, providing more area for periphyton growth, and creating microhabitats with low current speeds, finer substrates, and more detritus.

Sand substrates with litter were less productive (21.0 g/m^2) and had fewer species (Bass and Hitt 1977, 1978, Bass et al. 1979, 1980). Bare sand substrates had the least biomass (9.0 g/m^2) and the fewest individuals of invertebrate taxa, in the four Florida drainages. Clean sand is normally quite low in benthos (Bass and Cox 1985). The sand and sand/litter habitats are those most typical of small streams of the Gulf coastal plain from the Florida panhandle to Louisiana.

Snags and woody debris represent a relatively poorly studied habitat type that accounts for much invertebrate production in sand-bottomed streams. Benke et al. (1984) demonstrated that the invertebrate community living on snags was extremely important in terms of total invertebrate production in a

southeastern blackwater stream. However, snag habitat was not sampled or quantified in the studies on the four Florida drainages or in Carver's (1975) study. This habitat deserves intensive scrutiny, because Benke et al. (1985) have indicated that it is of great importance to higher level consumers (fishes). Other studies have documented the high invertebrate production associated with snag habitat [Ager et al. (1985) in the Apalachicola River, Smock et al. (1985) and Thorp et al. (1985) in Atlantic coastal drainages].

Invertebrate trophic groupings (Merritt and Cummins 1978) varied spatially, reflecting stream order position (Table 4). Upstream communities are dominated by collector/gatherers and scrapers. These groupings are also important downstream, but predators (piercers, engulfers) are also more in evidence.

Data in Bass and Hitt (1977, 1978), Bass et al. (1978, 1980), and Carver (1975) suggest that invertebrate biomass varies seasonally in Gulf coastal streams. Small and medium-sized streams (orders 1–4) have biomass minima in summer months, while larger streams (orders 5–6) have peaks of biomass in summer. This may reflect the different trophic bases of these stream sizes. The important resource base in small and medium-sized Gulf coastal streams is detritus entering streams, mostly in fall, winter, and spring (de la Cruz and Post 1977, Post and de la Cruz 1977). Consumers in downstream areas may be more dependent on primary producers within the stream itself (Vannote et al. 1980). The growing season for these producers would be spring and summer.

Invertebrate taxa other than oligochaetes and arthropods may also be important in Gulf Coast drainages. Everitt (1975) found several species of ectoprocts to be abundant in small acidic streams of Louisiana, usually found in association with macrophytes, which the ectoprocts used as attachment sites. Moore (1953) and Poirrier (1969) reported on sponges of Louisiana streams. They found *Spongilla lacustris*, *S. fragilis*, and *Heteromeyenia ryderi* in sand-bottomed streams.

In summary, invertebrate productivity varies spatially, being higher in areas with vegetation and detritus, lower in areas with clean sand bottoms. Invertebrate communities on woody snags may account for a large portion of stream invertebrate production. Sand-bottomed streams may have production minima in the low flow season (perhaps due to a lesser input of detritus in this season). Important taxa in sand-bottomed streams include elmids, chironomids, ephemeropterans, and oligochaetes. Larger rivers (with more autochthonous primary production) tend to have peaks of invertebrate production in the low flow season of summer and fall. Important taxa are all those of the sand-bottomed streams (except for elmids), as well as a number of predators. Perhaps higher productivity of downstream areas allows larger predator populations than are found in environments upstream.

Vertebrates

Fishes Variation among stream fish faunas is tied to the geologic and zoogeographic histories of these streams. Conner and Suttkus (1986), Gilbert

(1987), and Swift et al. (1986) presented detailed analyses of fish zoogeography in the waterways considered here. Table 5 lists the abundant fish species of Gulf coastal streams. Included are the freshwater forms; estuarine and marine species may penetrate downstream areas, especially in low water seasons (Felley 1987). Lee et al. (1980) provide summaries and references for taxonomies and natural histories of all these species. In general, streams west of the Suwannee drainage are primarily inhabited by minnows (Cyprinidae), sunfishes (Centrarchidae), and darters (Percidae), as well as suckers (Catostomidae). Predatory fish are not important numerically in most cases, but do comprise an important amount of the biomass (Bass and Hitt 1977, 1978, Bass et al. 1979, 1980, Bass and Cox 1985). The most important predatory species are spotted gar (*Lepisosteus oculatus*), bowfin (*Amia calva*), and largemouth and spotted bass (*Micropterus salmoides* and *M. punctulatus*). Streams of the Florida peninsula are largely lacking in minnows, suckers, and darters. For example, the ichthyofauna of the Peace, Hillsborough, and southern Withlacoochee rivers are dominated by sunfishes (Bass 1984). Gilbert (1987) presented a detailed discussion of zoogeographic patterns of peninsular Florida drainages.

There are relatively few endemic freshwater fish species limited to the medium-low gradient streams of the Gulf coastal plain. Many of the important species listed in Table 5 are quite widely distributed. Species limited to particular drainages covered by this chapter include a number of different shiners (*Notropis*), topminnows (*Fundulus*), and darters (*Etheostoma*). In general, these genera are considered to be ones that speciate readily, and many of the species are limited to only a few drainages.

There have been a number of investigations on the natural history and reproductive biology of some of the characteristic fishes of small Gulf coastal streams. These species include the longnose shiner *Notropis longirostris* (Heins and Clemmer 1975, 1976), Sabine shiner *N. sabinae* (Heins 1981), weed shiner *N. texanus* (Bresnick and Heins 1977, Heins and Davis 1984, Heins and Rabito 1988), blacktail shiner *N. venustus* (Heins and Baker 1987), naked sand darter *Ammocrypta beani* (Heins and Rooks 1984), Florida sand darter *A. bifascia* (Heins 1985), gulf darter *Etheostoma swaini* (Ruple et al. 1984), and saddleback darter *Percina vigil* (Heins and Baker 1989). Most of these species have a protracted breeding season when many egg clutches are produced, lasting from late spring through early fall (the season of lowest stream flow for most of the drainages in which these species live). Heins and Clemmer (1976) felt that such a long spawning season is adaptive in a highly variable environment, since it assures that no overwhelming fraction of the propagules will be destroyed by some dry period or sudden spate. Heins and Baker (1987) and Heins and Rabito (1986) further discussed life history strategies of particular species in these variable environments. They concluded that the high variability of Gulf coastal streams translates into strong selective pressures that affect life history traits in the species they studied.

Baker and Ross (1981), Ross et al. (1987), and Felley and Felley (1987) examined habitat use of fishes in Gulf coastal streams. Species in these as-

TABLE 5 Fish Species Characteristic of Small to Medium-Sized Streams of the Gulf Coastal Plain

Species	Stream Order		Current		Cover, Vegetation	
	Low	High	None	Some	Much	Little
Forms Found Throughout the Area Under Consideration						
Amia calva (bowfin)		+	+		+	
Anguilla rostrata (American eel)		+	+		+	
Esox americanus (grass pickerel)	+	+	+	+	+	
E. niger (chain pickerel)	+	+	+		+	
Notemigonus crysoleucas (golden shiner)	+	+	+		+	
Notropis chalybaeus (ironcolor shiner)	+		+	+	+	+
N. emiliae (pugnose minnow)	+	+	+	+	+	
N. maculatus (taillight shiner)		+	+		+	
Aphredoderus sayanus (pirate perch)	+	+	+		+	
Fundulus chrysotus (golden topminnow)	+	+	+		+	
Gambusia affinis (mosquitofish)	+	+	+		+	
Labidesthes sicculus (brook silverside)	+	+	+		+	+
Elassoma zonatum (banded pygmy sunfish)	+	+	+		+	
Lepomis gulosus (warmouth)	+	+	+		+	
L. macrochirus (bluegill)	+	+	+		+	
L. microlophus (redear sunfish)	+	+	+		+	
L. punctatus (spotted sunfish)		+	+		+	
Micropterus salmoides (largemouth bass)	+	+	+		+	+
Etheostoma fusiforme (swamp darter)		+	+	+	+	
Forms Widely Distributed, but Absent from Florida Peninsula						
Ichthyomyzon castaneus (chestnut lamprey)	+	+	+	+	+	+
I. gagei (southern brook lamprey)	+			+	+	+
Lepisosteus oculatus (spotted gar)		+	+		+	
Notropis texanus (weed shiner)	+	+	+	+	+	+

TABLE 5 *(Continued)*

Species	Stream Order		Current		Cover, Vegetation	
	Low	High	None	Some	Much	Little
N. venustus (blacktail shiner)	+	+		+		+
Pimephales vigilax (bullhead minnow)	+	+	+	+		+
Minytrema melanops (spotted sucker)	+	+	+		+	+
Moxostoma poecilurum (blacktail redhorse)	+	+	+	+		+
Fundulus notatus (blackstripe topminnow)	+	+	+		+	
F. olivaceus (blackspotted topminnow)	+	+	+	+	+	
Lepomis megalotis (longear sunfish)	+	+	+	+	+	+
Micropterus punctulatus (spotted bass)	+	+		+	+	+
Pomoxis annularis (white crappie)	+	+	+		+	
Forms Found in Various Coastal Drainages from Florida to East Louisiana						
Ericymba buccata (silverjaw minnow)		+		+		+
Notropis hypselopterus (sailfin shiner)	+		+	+	+	
N. longirostris (longnose shiner)	+			+		+
N. roseipinnis (cherryfin shiner)	+		+	+		+
N. signipinnis (flagfin shiner)	+		+	+	+	
N. welaka (bluenose shiner)		+	+		+	
Erimyzon tenuis (sharpfin chubsucker)	+	+	+		+	
Noturus leptacanthus (speckled madtom)	+			+		+
Fundulus euryzonus (broadstripe topminnow)	+		+	+	+	
F. notti (starhead topminnow)	+	+	+		+	
Ambloplites ariommus (shadow bass)	+	+		+	+	+
Ammocrypta beani (naked sand darter)	+	+		+		+
A. bifascia (Florida sand darter)	+	+		+		+
Etheostoma davisoni (Choctawhatchee darter)	+	+	+	+	+	
E. edwini (brown darter)	+	+		+	+	
Percina nigrofasciata (blackbanded darter)	+	+		+	+	
Forms Found in Western Louisiana and in Mississippi River Tributaries						
Hybognathus nuchalis (central silvery minnow)		+	+		+	+
Notropis fumeus (ribbon shiner)	+		+		+	+
N. sabinae (Sabine shiner)	+	+		+		+
N. umbratilis (redfin shiner)	+		+	+	+	+
N. volucellus (mimic shiner)		+		+	+	+
Ammocrypta vivax (scaly sand darter)	+	+		+		+
Etheostoma chlorosomum (bluntnose darter)	+	+	+	+	+	
E. gracile (slough darter)	+	+	+	+	+	
E. histrio (harlequin darter)	+	+		+	+	
E. proeliare (cypress darter)	+	+	+		+	
E. swaini (Gulf darter)	+			+	+	
Percina sciera (dusky darter)	+	+		+	+	
Forms Found Only in Florida (Peninsula and Panhandle)						
Lepisosteus platyrhincus (Florida gar)		+	+		+	
Fundulus escambiae (eastern starhead topminnow)	+	+	+	+	+	
F. lineolatus (lined topminnow)	+		+	+	+	
Leptolucania ommata (pygmy killifish)	+	+	+		+	
Acantharchus pomotis (mud sunfish)	+	+	+		+	
Elassoma evergladei (Everglades pygmy sunfish)	+	+	+		+	
E. okefenokee (Okefenokee pygmy sunfish)	+	+	+		+	
Enneacanthus chaetodon (blackbanded sunfish)	+		+	+	+	
E. gloriosus (bluespotted sunfish)	+	+	+		+	
E. obesus (banded sunfish)	+		+		+	
Lepomis auritus (redbreast sunfish)	+	+	+	+	+	+
Micropterus notius (Suwannee bass)		+		+	+	

Note. This is not an exhaustive list. Species are divided according to geographic distribution within the Gulf coastal plain, and by ecological preferences for stream order (low order = headwaters, high = downstream), current condition ("some" current corresponds to riffle habitat, there are essentially no "fast" current habitats within these streams), and amount of cover and/or vegetation.

Source. Information on particular species is from Baker and Ross (1981), Felley and Felley (1987), Lee *et al.* (1980), Page (1983), Pflieger (1975), and Ross et al. (1987).

semblages tend to be ecologically differentiated in terms of their uses of different stream orders, current speeds, and amounts of debris, cover, and vegetation. Table 5 categorizes fish species according to their preferences for differing states of these three environmental variables. Baker and Ross (1981) also found that water column position tended to differentiate cyprinids of a small coastal plain stream. Habitat use by species is relatively constant from year to year (Ross et al. 1987).

There may be large seasonal differences in habitat use by species. Felley and Felley (1987) showed that in the dry season, fish species tended to be more restricted in their use of habitats, and tended to depend more heavily on detritus as a food source. In the wet season, most species were found in a wide range of different habitats, and tended to feed more on invertebrates. Ross and Baker (1983) showed that several species feed heavily in flooded areas during the wet season, and that amount of flooding in the wet season may partly determine reproductive success in the following dry season. Finger and Stewart (1987) documented the importance of floods for fishes of medium-low gradient streams of southeastern Missouri. For fishes in these streams, the wet season seems to be a "season of plenty," while the dry season is a lean season (Schoener 1982).

Stream physicochemistry is closely related to fish production in medium-low gradient streams of the Gulf coastal plain. Kautz (1981) predicted fish biomass in various Florida streams based the streams' conductivities, total dissolved solids, and total nitrogen values. Bass and Hitt (1977, 1978) and Bass et al. (1979, 1980) investigated fish productivity in streams of the Florida panhandle. Using electrofishing techniques, they found that these streams produced between 5 and 14 kg of fish per hour of electrofishing (a standard method of determining fish biomass). These productivity estimates correspond to the relative invertebrate productivities of these streams (see previous section). The Blackwater River, producing an average of 0.6 g benthic invertebrates/m^2, had an average of 5.12 kg of fish per hour of sampling. The Choctawhatchee River system had the highest average value for benthic invertebrates (39.2 g/m^2) and for fish biomass (13.9 kg/h).

Reptiles and Amphibians Table 6 lists a number of reptiles and amphibians characteristic of medium-low gradient streams of the Gulf coastal plain, along with their ecological preferences for stream and river habitats (most often flowing water with little vegetation) or swamp–lake environments with abundant macrophytes (such environments are found in the floodplains and backwaters of these streams). Species found more often in streams include waterdogs (*Necturus* spp.), salamanders characteristic of small streams and springs (*Pseudotriton* spp., *Eurycea bislineata*), musk turtles (*Sternotherus* spp.), and map turtles (*Graptemys* spp.). A number of giant salamanders (*Siren* spp., *Amphiuma* spp.) are more likely to be found in vegetated backwaters and pools, as are most aquatic frog species (*Rana* spp.), mud turtles (*Kinosternon* spp.), and species of water snakes (*Nerodia* spp.). Several turtle species (*Pseu-*

TABLE 6 Amphibians and Reptiles Characteristic of Small to Medium-Sized Streams of the Gulf Coastal Plain

Species	Stream	Floodplain
Amphibians		
SALAMANDERS		
Gulf Coast waterdog (*Necturus beyeri*)*	+	
Alabama waterdog (*N. alabamensis*)	+	
Greater siren (*Siren lacertina*)		+
Lesser siren (*S. intermedia*)*		+
Dwarf siren (*Pseudobranchus striatus*)*		+
Two-toed amphiuma (*Amphiuma means*)		+
Three-toed amphiuma (*A. tridactlyum*)		+
Southern dusky salamander (*Desmognathus auriculatus*)	+	+
Mud salamander (*Pseudotriton montanus*)*	+	
Red salamander (*P. ruber*)	+	
Two-lined salamander (*Eurycea bislineata*)	+	+
Three-lined salamander (*E. longicauda*)	+	+
Dwarf salamander (*E. quadridigitata*)		+
Eastern newt (*Notopthalmus viridescens*)*		+
FROGS		
Cricket frog (*Acris gryllus*)*	+	+
Bullfrog (*Rana catesbiana*)		+
River frog (*R. hecksheri*)		+
Pig frog (*R. grylio*)		+
Bronze frog (*R. clamitans*)	+	+
Southern leopard frog (*R. sphenocephala*)		+
Reptiles		
ALLIGATORS AND CROCODILES		
American alligator (*Alligator mississippiensis*)	+	+
TURTLES		
Snapping turtle (*Chelydra serpentina*)*	+	+
Alligator snapping turtle (*Macroclemys temminckii*)	+	+
Stinkpot (*Sternotherus odoratus*)	+	+
Razorback musk turtle (*S. carinatus*)	+	+
Loggerhead mud turtle (*S. minor*)*	+	
Striped mud turtle (*Kinosternon baurii*)		+
Eastern mud turtle (*K. subrubrum*)*		+
False map turtle (*Graptemys pseudogeographica*)*	+	
Barbour's map turtle (*G. barbouri*)	+	
Yellow-blotched map turtle (*G. flavimaculata*)	+	
Mississippi map turtle (*G. kohni*)	+	
Black-knobbed map turtle (*G. nigrinoda*)*	+	
Ringed map turtle (*G. oculifera*)	+	
Alabama map turtle (*G. pulchra*)	+	
Slider (*Pseudemys scripta*)*	+	+

TABLE 6 *(Continued)*

Species	Stream	Floodplain
River cooter (*P. concinna*)*	+	+
Cooter (*P. floridana*)*	+	+
Florida softshell (*Trionyx ferox*)	+	+
Smooth softshell (*T. muticus*)*	+	+
Spiny softshell (*T. spinifer*)*	+	+
SNAKES		
Mud snake (*Farancia abacura*)*	+	+
Rainbow snake (*F. erytrogramma*)*	+	+
Green water snake (*Nerodia cyclopion*)*		+
Plainbelly water snake (*N. erythrogaster*)*	+	+
Southern water snake (*N. fasciata*)*	+	+
Diamondback water snake (*N. rhombifera*)		+
Brown water snake (*N. taxispilota*)	+	+
Graham's crayfish snake (*Regina grahami*)		+
Glossy crayfish snake (*R. rigida*)*		+
Cottonmouth (*Agkistrodon piscivorous*)*	+	+

Note. This is not an exhaustive list. The list does not include species that are found in these streams during only one period in their lives (e.g., terrestrial amphibians that may breed in these habitats). Forms are characterized ecologically, based on whether they are more likely to be found within the stream, or in floodplain pools, or both.
*Species with more than one subspecies in covered areas.

Source. Ecological information summarized from Cochran and Goin (1970), Conant (1975), Mount (1975); nomenclature follows Collins et al. (1982).

demys spp. and *Trionyx* spp.) may be found in either type of environment, as may mud snakes (*Farancia*) and some water snakes.

Most of these reptiles and amphibians are widely distributed and many are represented by several subspecies in the geographical area covered by this chapter. Auffenberg and Milstead (1965) discussed the effect of Pleistocene sea-level changes on speciation and zoogeography of reptiles in the southeastern United States. In particular, they hypothesized that the Gulf Coast served as a "corridor" of temperate climatic conditions that allowed exchange of species between the Florida peninsula and Texas. Only a few species are restricted to particular drainages (as are some species of fishes, for example). In particular, a number of map turtles (Barbour's, yellow-blotched, black-knobbed, Alabama) are confined to particular drainages, and the false map turtle has evolved into several subspecies confined to different drainages. Much like fishes, these map turtles are ecologically confined to rivers and streams, which may permit isolation and speciation.

Few researchers have concentrated on the ecology of reptiles or amphibians in Gulf coastal streams. Shively and Jackson (1985) investigated the ecology of the Sabine map turtle (*Graptemys ouachitensis sabinensis*) in Whisky Chitto

Creek, a tributary of the Calcasieu River. They found that this species is limited to areas with many snags, which provide sunning spots and substrate for growth of green algae, a food of this turtle.

REPRESENTATIVE AQUATIC COMMUNITIES

Medium-low gradient streams of the Gulf coastal plain share a number of physicochemical characteristics. All are warm and, except for extreme headwaters, water flows year-round. Stream beds typically consist of sand or sand and clay, and pH and dissolved solids tend to be quite low. In most such streams, oxygen levels are high, typically staying near 80% saturation. Low levels of dissolved oxygen may occur in spring-fed streams, since groundwater is characterized by low dissolved oxygen. Periodic low flow in tidally affected streams may result in transient low oxygen (Felley 1987).

Seasonal variability in these streams relates to flow regimes. All streams experience a dry and a wet season, and for most streams considered here, the wet season is winter and spring. During the wet period, flow is high and streams tend to flood, while flow drops off in summer and fall. This change in flow regime affects temperature, pH, concentrations of dissolved solids, and oxygen levels, all of which show seasonal differences reflecting seasonal flow patterns.

There is spatial variation in stream physicochemistry, tied to stream order. In general, and as predicted by Vannote et al. (1980), headwaters are more variable in flow and physicochemical variables. Downstream areas tend to integrate the effects of many headwater streams and are less variable.

The most important primary producers of these streams are the terrestrial and emergent plants of the stream edges and surrounding floodplains. Detritus generated by these communities is the principal food base of most streams. Primary production within the stream itself seems mostly tied to algae and aufwuchs that grow on snags. Submerged macrophytes are important in the most downstream portions of these drainages, in canals and floodplain ponds—all areas where current is low. Where they occur, submerged macrophytes create habitats rich in animal biomass and diversity. However, the shifting sand bottom and high flow variability of typical streams apparently limit the distribution of submerged macrophytes.

The importance of snags and woody debris has been demonstrated for aquatic invertebrates, fishes, and reptiles. Invertebrate diversity and biomass is high on snags (Ager et al. 1985, Benke et al. 1984). Fish depend on these invertebrates for food (Benke et al. 1985) and some species seem to prefer snags and cover for protection from predators. At least one reptile species (Sabine map turtle) is partially limited in its distribution by the occurrence of snags.

Seasonal changes in flow rates are reflected in the biology of particular fish species. Some forms take advantage of spring floods to forage in surrounding floodplains (Ross and Baker 1983, Finger and Stewart 1987). In the

dry season, species tend to be more limited in their distributions; Felley and Felley (1987) found that species were constrained in their distribution to "exclusive environments," perhaps areas where they were safest from predators or could avoid competitors. They also found that food seemed most limiting in the dry season.

There are important geographical differences from the typical ecosystem outlined above, which essentially represents a sand-bottomed stream (Beck 1965). Larger rivers (here including only the Escambia and Choctawhatchee rivers in their downstream reaches) may have higher levels of primary production within the stream. Invertebrate production is highest in summer and fall. Judging from upstream–downstream comparisons in the Calcasieu drainage, larger rivers should be much less physicochemically variable than upstream, sand-bottomed reaches. Calcareous streams of the Florida peninsula are under a different hydrological cycle, because the low flow season is winter and spring. These streams have high levels of dissolved substances and nutrients and more submergent macrophytes than do either sand-bottomed streams or large rivers. There are some invertebrates limited to these streams (primarily gastropods), and fishes are mostly sunfishes and topminnows.

RESOURCE USE AND MANAGEMENT IMPACTS

Past and Future Effects

Originally, the stream systems discussed in this chapter drained pine and mixed pine–hardwood woodlands. In the 19th century, much of this forest was logged, and crops (cotton, corn, etc.) were planted on the cleared land (Hilliard 1984). This was doubtless a time when waterway siltation increased. Much of the planted area has now been returned to forest, in the guise of pine plantations. Thus, in some sense the streams covered in this chapter now drain landscapes more similar to those before human exploitation.

In the 20th century, industrialization and population growth have introduced a greater diversity of impacts than existed previously. Today, human impacts include pollution of waterways by human wastes, by pesticides, and by industrial wastes (such as those originating from pulp mills), effects of forestry and agricultural practices, and effects related to direct modification of waterways.

Municipal effluents (sewage) produce lowered oxygen levels, nutrient enrichment (addition of nitrates and phosphates), and raised bacterial counts. The Louisiana Department of Environmental Quality (1984) lists various waterways, streams, and stream sections that receive high levels of municipal effluents. Point sources of municipal sewage affect all the Louisiana streams discussed in this chapter. The effects of sewage on stream systems are well known (Krenkel and Novotny 1980). In nutrient-poor streams with normally high oxygen levels, the effects of sewage on communities could be expected to be quite dramatic. Invertebrate community composition in sand-bottomed

streams is changed by organic pollution. Beck (1954) illustrated a method of using presence/absence of particular invertebrate species to indicate organic pollution. However, nutrient enrichment alone may not always produce a change in community composition. Lackey and Morgan (1960) and Lackey and Putnam (1965) investigated the effect of phosphorus enrichment (through phosphate mining) on microbial and blue-green algal populations. Comparing the phosphate-poor Santa Fe River with the Peace River (phosphate-rich), they found populations in the Peace River to be hundreds of times greater. Yet the species were no different in the two streams, suggesting that while prokaryote community structure would be affected by phosphate enrichment, species composition would not be so affected.

Industrial wastes affect many Gulf coastal streams. The Louisiana Department of Environmental Quality (DEQ) monitors substances that identify industrial effluents and agricultural runoff, including heavy metals (arsenic, cadmium, copper, mercury), and PCBs. DEQ data (1975 to present) on Louisiana streams covered in this chapter indicate levels of these substances ranging from 0 to 20 μg/L. Lowest levels were found in the Tangipahoa and Tickfaw rivers, two recreationally important waterways. Similar levels were recorded from the Florida rivers considered here (data from Florida Department of Environmental Regulation, mid-1970s–present). Lafleur (1956) investigated the effects of pulp mills on invertebrate communities in the Calcasieu drainage. He found that mayflies were potential indicators of pulp mill pollution, because they seemed intolerant of the physicochemical conditions produced by these mills. Herrman (1981) discussed the physicochemical effects of pulp mills in certain warmwater streams; these effects may be generalized to Gulf coastal streams. Some Florida waterways have been heavily affected by municipal and industrial pollution. Bass (1984) considered the small Fenholloway River to be "ruined." He reviewed and summarized studies on pollution and pollution abatement programs on the Escambia River, a system he felt was improving due to these programs.

Agricultural and silvicultural practices affect these waterways. Clear-cutting of pine may result in siltation of adjacent waterways (Gibbons and Salo 1973). Siltation and community responses to it have apparently been little studied in Gulf coastal regions. Some effects may be quite local. For example, flushing of rice fields in summer produces pulses of turbidity and oxygen demand in the lower Calcasieu drainage (during a period of the year when turbidity is usually low and primary production high). The Louisiana DEQ Office of Water Resources (1984) felt that agricultural/silvicultural effects were a significant source of water-quality problems along some streams, but were often minor in comparison to other insults acting upon many Louisiana streams.

Some impacts affect small streams directly, as these waterways become impounded or otherwise managed. Woodruff et al. (1963) listed a series of channel control or impoundment facilities that would affect the streams of the Florida panhandle (from the Perdido River to the Santa Fe River). These included four proposed reservoirs on the Ochlockonee River, one on the

Choctawhatchee and one on the Yellow River. Channelization of waterways involves a series of changes, generally deleterious to native biota (see Henegar and Harman 1971). Habitat diversity, which is of demonstrated importance to fishes, is decreased (Gorman and Karr 1978). The waterway is so constructed as to produce pulses of high water as runoff is flushed away. Woody structure (of importance to these ecosystems) is removed. All of these effects reduce biotic diversity in these streams and add physicochemical stresses uncharacteristic of small southeastern streams. These may present conditions to which local species are poorly adapted. In the Calcasieu drainage, fishes inhabiting channelized waterways are forms more characteristic of physicochemically stressful prairie streams (streams with widely variable flow and temperatures and little cover (Matthews and Hill 1980)), including the red shiner (*Notropis lutrensis*), black bullhead (*Ictalurus melas*), mosquitofish (*Gambusia affinis*), and green sunfish (*Lepomis cyanellus*).

There are a number of endangered species, threatened species, and species of special concern inhabiting the streams covered in this chapter. Endangered and threatened species include the American alligator and two darters confined to one or two small drainage systems (U.S. Fish and Wildlife Service 1986). The Okaloosa darter (*Etheostoma okaloosae*) is confined to a few small streams draining into Choctawhatchee Bay, Florida (Gilbert 1978), and the bayou darter (*E. rubrum*) is found only in the Bayou Pierre system, Mississippi (Suttkus and Clemmer 1977). The recently described blackmouth shiner, *Notropis melanostomus*, is found only in the Blackwater and Yellow river systems; its life history is being intensively studied by the Florida Game and Freshwater Fish Commission (Bortone 1989). Several species of map turtles and the alligator snapping turtle are being considered for designation as endangered species. Beccasio et al. (1982) provide an ecological inventory (incorporating references pertinent to endangered or threatened species) covering some areas included in this chapter. In particular, their inventory covers Louisiana streams draining into Lake Pontchartrain, and streams of the Florida panhandle.

A special problem is associated with streams of the Florida peninsula and to a lesser extent other streams covered here. Introduced fish species (Courtenay and Stauffer 1984) are actively displacing native species in this area. Wilson and Porras (1983) discuss some of the problems facing south Florida's herpetofauna.

Unique Resources and Management Problems

The sand-bottomed streams of the Gulf coastal plain represent a valued recreational resource. Portions of the Tangipahoa and Tickfaw rivers (two Louisiana scenic waterways) are popular with canoeists from the Baton Rouge and New Orleans areas. In southwestern Louisiana, Whisky Chitto Creek is also a popular recreational waterway. In Mississippi, portions of Black Creek have been designated as wild and scenic rivers. In Florida, the Blackwater River and Yellow River are both protected by national forests or other federal

lands, and both have been proposed for consideration as national scenic rivers. Bass (1984), reviewed literature on these streams, noting that their popularity with fishermen and canoeists had produced accumulations of trash, beer cans, and so on. Waste left by campers and fishermen may not have much effect at the ecosystem level, but it represents a management problem for those responsible for maintaining the waterways for the public. A more serious problem is the clearing of snags and logs to "improve" these waterways for boaters.

The major importance of snags and other woody material in these streams must be understood and accepted. The typical small stream ecosystem of the Gulf coastal plain revolves around debris and large woody snags. The high productivity of this habitat was demonstrated in the Apalachicola River by Ager et al. (1985). Angermeier and Karr (1984) investigated the effects of changing amounts of structure (snags and debris) in a midwestern stream. Benke et al. (1984, 1985) and Thorp et al. (1985) demonstrated the importance of snag habitat in waterways of the Atlantic coastal plain. Thus, a major management aim should be to retain and enhance snag habitat, because the animal community and a large segment of the plant community depend on these snags. This will require rethinking of flood management and navigation improvement programs. These programs usually include removal of snags, since snags tend to impede flow (Marzolf, 1978).

The major importance of seasonal floods to these streams must also be understood and accepted. The biota of these streams have evolved in an environment that floods seasonally. Alterations that reduce flooding may be expected to cause ecosystem-level changes in these streams. Use of medium-low gradient streams and associated floodplains should be approached with the attitude that seasonal flooding is normal and proper. Such an attitude translates into land use policies that forbid encroachment onto floodplains and that promote reduction of soil erosion and consequent catastrophic floods. Massive projects to prevent floods are inappropriate in these streams. In the medium- and low-gradient streams covered in this chapter, flood control (if absolutely necessary) may be better effected by constructing check dams in extreme headwaters. Ebert and Knight (1981) outlined such a flood-control program, along with a fish habitat enhancement program, in a Mississippi watershed.

Unique Natural and Induced Impacts

Important stressors in the small stream ecosystems covered in this chapter have already been outlined. Year-to-year variation in rainfall and in seasonal flooding may be counted a stress. This variability may determine reproductive success of some species (Ross and Baker 1983). For fish species, the dry season may represent a period of shortage, for example, of food and appropriate habitat (Felley and Felley 1987). However, the typical communities that inhabit these streams are (by definition) composed of species that are able to maintain populations in the face of such events. Human-induced

impacts present these communities with events to which many species are not adapted. Pollutants (e.g., heavy metals and organic chemicals), high nutrient levels, and low oxygen levels may all induce changes in the species composition of these communities. Removal of substrates for attachment of epiphytic plants and logging or clearing of streamside communities both deprive these streams of necessary primary production. Channelization produces conditions that may favor wholly different communities. Human impacts, as opposed to natural ones, may produce conditions that can wipe out a species in a drainage. Thus, a darter species that inhabits a single drainage is not likely to be vulnerable to short-term climatic events, but is vulnerable to short-term environmental changes due to human activities.

RECOMMENDATIONS FOR FURTHER RESEARCH AND MANAGEMENT

Both research and management should, in the future, concentrate on those aspects that make Gulf coastal streams unique. These include the low dissolved solids and low pH condition of these streams. What effect does adding dissolved substances have on the biota? Are any species limited by these physicochemical conditions? Which ones? Such "sensitive" species would be most vulnerable to changes in the environment. Heins and Baker (1987) and Heins and Rabito (1988) have shown that life history and population structure of certain fishes respond to differences in the physicochemical environments of these streams. How does the stream community interact with the floodplain community? Apparently, some species are intimately tied to both communities, while others are not (Ross and Baker 1983, Finger and Stewart 1987). What are the important producers within these streams, and are they limited by hard substrate (snags) as so many studies show (Ager et al. 1985, Benke et al. 1984, 1985, Thorp et al. 1985)? What are the relative importances of within-stream producers and allochthonous inputs of fixed carbon? What are the patterns of spatial and temporal variation in the importance of these two sources of primary production? How do different trophic levels respond to the low-water/high-water cycle? These are ecosystem levels that require the intensive study of a representative Gulf coastal drainage. A relatively large drainage, such as the Pascagoula system, should be intensively investigated with a view to answering such questions as those outlined above.

Each of these questions has management implications. Management recommendations at this stage must be relatively crude and perhaps obvious: Do not channelize, leave woody material and snags within the stream, do not build in the floodplain, restrict municipal/industrial discharges and enforce adherence to adequate treatment level to maintain stream quality. These recommendations would benefit any stream ecosystem. Study of medium-low-gradient streams at the ecosystem level will allow more subtle management decisions.

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CHAPTER 11

Using Benthic Macroinvertebrate Community Structure for Rapid, Cost-Effective, Water Quality Monitoring: Rapid Bioassessment

David R. Lenat, NC Division Environmental Management, Water Quality Section, Raleigh, NC
Michael T. Barbour, Tetra Tech. Inc., Owings Mill, MD

INTRODUCTION

The scientific literature relating to water pollution biology frequently describes very time-consuming and labor-intensive, surveys. Such surveys, however, may not represent the most typical kind of biological monitoring effort. Most state agencies are responsible for water quality monitoring on thousands of streams; this situation is also typical of many areas outside the United States. To expend large amounts of time and money on a single stream is equivalent to ignoring water quality problems in many other streams.

The development of more cost-effective biological monitoring strategies has come to be known as "Rapid Bioassessment". The term "Community Assessment Approach" has also been used in this context because of a focus on the evaluation of community structure and function. The emphasis in such monitoring is on obtaining "rapid" results in order to expedite both assessment of water quality problems and any subsequent management decisions. Specifically, the goal is to expend the minimum amount of effort required to get reproducible, scientifically valid results. Most rapid bioassessment programs are designed to go from field

collections (3 to 5 sites) to a report in five working days. Rapid bioassessment also implies some shortcut techniques relative to traditional collections. This shortcut usually involves qualitative/semiquantitative sampling, or processing a targeted number of organisms/site.

One of the charges of the Societas Internationalis Limnologiae's Biological Monitoring Working Group involves education and sharing of information on water quality assessment methods. Many organizations with no prior biological monitoring experience will be looking to adopt rapid bioassessment methods; other agencies will be interested in adding rapid bioassessment to their existing program. It should be taken as part of the Working Group's charge to think about what will work in parts of the world where resources, personnel, and taxonomic knowledge are minimal.

This paper addresses the many choices to be made in setting up a rapid bioassessment program, with discussion of the advantages/disadvantages of each choice. We have not included all of the approaches used in North America, but we have reviewed a representative cross-section of "rapid" water quality assessment techniques. Procedural recommendations are based on the type of habitat sampled, the type of data required, available sampling equipment, and available taxonomic skill. The most important decisions involve the level of taxonomy and the general sampling method.

This is an "opinion" paper and reflects our biases. It borrows from many recent publications, including Plafkin et al. (1989), Lenat (1988, 1990), and Resh and Jackson (1993). Other important sources of information include bioassessment programs in Maine (Susan Davies/David Courtemanch), Ohio (Jeff DeShon), Arkansas (Bruce Shackelford) and New York (Robert Bode). Discussion will be limited primarily to stream/river benthos and will focus on North American work.

CHOOSING A RAPID BIOASSESSMENT METHOD

General Considerations

Before establishing a rapid bioassessment program, some general decisions must be made about what portion of the aquatic community will be collected, how to locate individual samples within a stream reach, and

quality assurance methods. To some extent, these desicions may be influenced by existing programs in each geographic area.

Which aquatic assemblage?

The organisms most commonly used in stream water quality monitoring are periphyton, fish, and benthic macroinvertebrates. Both Plafkin et al. (1989) and Karr (1991) discuss the use of different aquatic groups and this topic is not treated in detail here. Ideally, a bioassessment agency should have the capability of using all of these groups in biological monitoring, as each additional group will contribute further useful information towards an assessment of water quality. The Kentucky Division of Water is one of the few biological monitoring agencies which routinely uses periphyton, fish, and macroinvertebrate collections; they have found that such integrated monitoring yields results superior to the usual single-group collections (Mike Mills, personal communication). The U.S. Environmental Protection Agency (E.P.A.) also has proposed using all three groups for lake and stream monitoring (Paulsen et al. 1994) Periphyton collections are particularly useful because of the many indicator assemblages (Patrick 1994): enrichment, brine, etc. Fish are especially useful in relating changes in habitat quality and showing changes in the abundance of game fish. The Index of Biotic Integrity (IBI: Karr et al. 1986) has been very successful in the Midwest for relating fish community structure to water quality. The success of the IBI approach is being copied by investigators working with benthic fauna (Ohio EPA 1989, Shackleford 1988).

Each group of aquatic organisims has been commonly used for water quality monitoring. Further discussion in this paper focuses on benthic macroinvertebrates, but does not imply that invertebrates are always the best choice. The selection of a group of aquatic organisms is most strongly influenced by an agency's focus, the known sensitivity of the group, available taxonomic skills, and comparability of existing data bases.

Location of individual samples.

Some biological monitoring agencies collect macroinvertebrate samples from what appears to be a representative habitat, while other agencies sample either the "most productive habitat" (Plafkin et al. 1989) or any high current habitat with "structure" (Lenat 1988). The latter approach usually means riffle sampling, although snags and root mats will be sampled in naturally sandy streams. The choice of sampling location affects the ability of an investigator to separate habitat effects from water quality effects.

When attempting to measure water quality impacts, most investigators attempt to minimize between-site differences in habitat. For this reason, benthic macroinvertebrate sampling must always be accompanied by some measurement of habitat characteristics. Changes in habitat quality, however, often cannot be avoided in some studies, particularly investigations of nonpoint source pollution. In these cases, habitat degradation may be the major problem under investigation. It is possible, however, that sampling the most productive habitat (least stressed) may minimize between-site habitat differences and focus on between-site differences in water quality. This hypothesis reflects the North Carolina experience (see discussion below), but it is largely untested.

EPA Rapid Bioassessment protocols (Plafkin et al. 1989) emphasize collections from the most productive habitat. It is thought that such collections allow between-site evaluations of habitat quality, with fewer complications from between-site differences in habitat diversity. These EPA protocols use an analysis system (largely untested) that attempts to partition adverse biological changes into water quality effects, habitat quality effects, or combined effects. This system incorporates an overall evaluation of habitat structure that produces four habitat quality ratings: "comparable" (to the control), "supporting", "partially supporting" and "nonsupporting".

The most commonly encountered habitat changes are related to sediment inputs from both local erosion (often the cutting of stream banks) and erosion within the stream's catchment. Sediment tends to accumulate in pool, run, and bank areas, and pass through high-current habitats. The scouring effect of this transient sediment is not well understood. The negative effects of scour also vary with flow, being most severe during periods of high flow (Lenat et al. 1981).

Standardized sampling methods have been developed largely for shallow (wadable) streams. Organizations that require the same sampling technique for a wider variety of stream types often use artificial substrates (e.g., Maine). Location of samples in larger rivers requires considerable judgment on the part of the collector. Under high to normal flow conditions, the diversity of organisms of shore/bank areas in deeper streams and rivers may be much greater than the diversity of unstable midstream substrates. In North Carolina's coastal plain rivers, we have found that large (i.e., stable) snags in areas of current have much greater diversity than other microhabitats (Benke et al. 1985).

QA/QC.

The defensibility of any method depends on some evaluation of the method's variability. For this reason, all aspects of a bioassessment program should be evaluated by a Quality Assurance/Quality Control program. QA/QC procedures are particularly important for organizations that are initiating a bioassessment program. A useful reference for setting up QA/QC programs is the proceedings of a recent workshop on Quality Assurance programs (Hart 1990). This document discusses QA/QC elements and the requirements for testing the validity of ecological surveys.

Development of a detailed Standard Operating Procedures (SOP) manual is important for the assurance of uniform sampling methods, especially if there are changes in collection personnel. Any monitoring group also should incorporate periodic validation tests to show that they can verify water quality conditions in both pristine and polluted areas. A few such tests will go a long way towards building confidence in the ability to detect changes in water quality.

Using a reference site to calibrate different investigator teams is a commonly used QA procedure. A reference site may reflect typical conditions in a catchment, but minus a pollutant of interest. Reference sites also should be located in a largely undisturbed catchment. Such relatively pristine streams may be used to define the conditions for each ecoregion (Hughes and Larsen 1988, Hughes et al. 1994). Periodic sampling of ecoregion reference sites may be used to test for any seasonal changes in the benthic macroinvertebrate community.

Most invertebrate sampling assumes that collections are representative of a larger stream segment. This assumption may be tested by sampling two reaches within a fairly homogeneous stream segment. The use of different collection teams may be tested by "overlap" sites (sites sampled by both teams). Overlap sites are also useful in comparing results from different agencies. Alabama and Mississippi are using overlap sites as part of their ecoregion testing; likewise, North Carolina and South Carolina will be establishing some overlap sites.

Taxonomic QA/QC is difficult, as it may require consultation with authorities outside of the local organization. Part of the difficulty is the potential for conflict in establishing what is a "correct" identification. However, the accuracy of identifications is most commonly assessed by comparing results with regional experts, thereby showing that identifications are consistent with those of other established taxonimists. Within-group exchanges (if a group contains more than one taxonomist) also are essential in maintaining taxonomic consistency.

Comparability with existing data bases

Contiguous states might share similar ecoregions, i.e., to have areas where they will have similar biological expectations; this would warrant the use of similar biological monitoring approaches. In such situations, existing approaches might be adopted with minimal developmental work. Alabama and Mississippi are examples of state agencies that are attempting to share the costs of sampling ecoregion reference sites. Similarly, Oregon, Washington, and Idaho are cooperating in the development of bioassessment programs, and Delaware, Maryland, and Virginia are evaluating common elements in their coastal plain aquatic ecosystems.

Making Choices

Setting up a rapid bioassessment program involves some difficult choices on level of taxonomy (e.g., order, family, genus, or species), sampling strategy, and sampling equipment. There are many "correct" choices and it is unlikely that any two water quality agencies will have identical programs. The most appropriate choices may also vary depending on the needs of individual surveys.

Taxonomy

Most biological monitoring techniques are dependent on the correct identification of the organisms collected. Better taxonomy can be expected to produce more accurate results, with a better ability to detect subtle changes in water quality. A biological monitoring group should always strive to increase its level of taxonomic proficiency, and should interact with regional taxonomic experts. In the long run, much time and money can be saved by hiring qualified and experienced taxonomists; if this is not possible, monitoring agencies should develop adequate training programs. In establishing a new biological monitoring unit, we suggest building in a training phase before starting pollution assessment work. The training phase would be completed when taxonomic QA checks reach some acceptable level. Adequate taxonomic skills also are required to pass other QA/QC checks, especially the validation of known high quality sites.

At the coarsest level of taxonomy, personnel can be trained to identify orders of aquatic insects and then estimate taxa richness per order. This type of taxonomy can be done with a hand lens (as in Cummins and Wilzbach 1985); it is used with the Operational Taxonomic Unit (OTU) approach of Mason (1979) and the Sequential Comparison Index of Cairns and Dickson (1971). With this level of taxonomy, it is particularly important that investigators prove that they can verify unpolluted conditions. Such approaches are most appropriate for citizen monitoring groups (Klein 1983).

Family level taxonomy has been recommended by many investigators, including Kaesler and Herricks (1979), Osborne et al. (1980), Furse et al. (1984), and Hilsenhoff (1988a). EPA's Rapid Bioassessment Protocol II (Plafkin et al. 1989) also was set up using family-level identifications. It is argued that less taxonomic training is required to identify macroinvertebrates at the family level, thus minimizing costs of hiring and/or training personnel. Furthermore, there may be a large savings in sample processing time with family-level identifications; most organisms can be identified in the field to a family level. This "reduction in sample processing time" argument is most valid for personnel with limited expertise; more experienced taxonomists can identify many organisms to the genus/species level almost as fast as to the family level. The latter statement is based on the experience of the authors, as well as conversations with many working taxonomists. However, such taxonomic

proficiency may require 3-4 years of experience in collecting and identifying aquatic macroinvertebrates.

The use of family-level identifications may be a compromise between production of rapid results and the accuracy of water quality evaluations. Analysis of family-level data must make certain assumptions about the composition of species assemblages and their ecological sensitivities. For example, an identification of Hydropsychidae will usually assume the presence of relatively tolerant *Hydropsyche* and *Cheumatopsyche* species, although a much more intolerant assemblage of Hydropsychidae might actually be present.

Genus/species level identifications clearly increase the precision of site classifications (Resh and Unzicker 1975, Furse et al. 1984, Hilsenhoff 1982, Rosenberg et al. 1986), and such identifications are essential for the use of pollution "indicator assemblages" (Resh 1979, Simpson and Bode 1980). The use of a biotic index also is vastly improved with more precise identifications (Hilsenhoff 1988a). Family-level identifications may be inappropriate for examinations of changes over time, assessment of the length of a recovery zone, and the determination of special high quality waters. Family-level identifications are primarily useful for one-time assessments of water quality in a specific area, or in the ranking of sites for additional study. If a monitoring agency intends to gradually build a large regional data base (for future between-site and between-date comparisons), then genus/species level identifications are more appropriate. Family-level identifications, therefore, may save time in the short run, but become inefficient for long-term monitoring efforts.

If a biological monitoring group has very limited resources, they may wish to focus taxonomic expertise on certain intolerant (and easily identified) groups. North Carolina has developed an abbreviated "EPT" collection method, characterized by fewer samples (4) per site and collections limited to the Ephemeroptera, Plecoptera, and Trichoptera. In other geographic areas, a different set of intolerant organisms might be selected, as long as these organisms were relatively large, long-lived, easy to identify, and diverse at regional reference sites.

Species-level identification are most troublesome for specimens that must be slide-mounted for definitive identifications, i.e., Chironomidae (midges) and Oligochaeta (worms). However, biological monitoring results will be greatly enhanced by the identification of these groups. Taxa richness of Chironomidae may not be linearly related to water quality (Lenat 1983), but their indicator value offsets such problems. Information on these groups is a crucial step in deducing both the type of pollution as

well as level of stress. Chironomid taxonomy can be very difficult, especially if expert help is not readily available. However, the literature on chironomid taxonomy and ecology is steadily improving; two recent examples include Wiederholm (1983) and Hudson et al. (1990) There are many methods that can be used to speed up identification of Chironomidae, especially sorting before slide-mounting specimens, subsampling, and learning to recognize some genera without slide mounting of specimens.

Sampling method

The selection of a sampling method is probably the most difficult choice in establishing a rapid bioassessment method. Generally speaking, a sampling method is made "rapid" by some restriction on the number of organisms picked and identified. An investigator also may restrict the type of organisms selected (EPT sampling, chironomid pupal exuviae, etc.). Restrictions on the number of organisms to be identified can be acomplished either by using an ordinal scale (rare, common, abundant, etc.), or by subsampling the organisms at each location. Sample splitters are sometimes used, often with the idea of subsampling until reaching some target number of organisms. With any type of subsampling, the assumption is made that all organisms have the same probability of being selected. Both ordinal-scale counting and subsampling de-emphasize a quantitative measurement of abundance per unit area, although they may still include quantitative measurement of abundance or dominance. Abundance per unit area is a highly variable measurement spatially and temporally, even in the absence of any water quality change (Resh and Rosenberg 1989, Lenat 1990).

The concept of rapid bioassessment has embraced a variety of sampling strategies, while adhering to certain basic concepts. At one end of the spectrum, Plafkin et al. (1989) recommended a single-habitat sample (this may be a composite collection), using a subsampling technique to withdraw approximately 100 organisms. At the other end of the spectrum, Lenat (1988) suggests multiple-habitat collections with ordinal-scale counts. The selection of an appropriate sampling strategy will depend on many factors, including the purpose of the survey, the methods used by nearby monitoring groups, the expertise of collecters, preference for quantitative versus qualitative data, and the characteristics

of streams in a particular geographic area. Some agencies have attempted to combine strategies by supplementing standardized collections with additional "visual" sampling from large rocks and logs.

Multiple-habitat collections more completely census the invertebrate fauna than single-habitat collections. Method-testing in Plafkin et al. (1989) indicated that 100-count samples (from riffles) collected 35 - 68% (n = 5) of the taxa in multiple-habitat samples. The relative variability of the two methods has not been adequately evaluated; each method will be certain to have its own proponents, based largely on their unquantified experience in collecting invertebrate samples. Additional testing is needed to evaluate the reliability of site classifications using each approach.

Multiple-habitat sampling must be paired with either qualitative (presence/absence) or semiquantitative (ordinal) enumerations. Semiquantitative sorting of samples usually puts taxa into categories (absent, rare, common, or abundant), depending on their relative abundance in the final sample (Lenat 1988). Organisms are picked out of samples "in proportion to abundance", or until no new taxa are encountered. This process may seem too variable to some investigators, because the stopping point is not readily apparent, but it has worked well in practice for North Carolina Division of Environmental Management (DEM) biologists. While such a sorting technique requires (or works better) with experienced people, North Carolina often uses nonspecialists as part of collecting teams without affecting data quality.

Another sampling choice is whether samples should be sorted in the field or in the lab. Lab sorting of samples should result in more efficient removal of organisms, especially the smaller (less conspicuous) taxa. The laboratory also provides a more controlled environment for sample processing and permits more detailed quality assurance procedures. However, field sorting produces less battered specimens and has immediate feedback on the adequacy of samples. The problem of sorting efficiency can be dealt with by "saturation" sampling: many samples and many habitats. There are also some techniques that help in field sorting: field preservation, elutriation, and special fine-mesh samplers (Lenat 1988). North Carolina biologists regularly collect about 25 chironomid taxa per site (maximum around 40 per site) using these techniques.

Sampling gear

In setting up a biological monitoring program, decisions must be made concerning the type of sampling equipment and the mesh size used to process samples. Most benthos workers (in streams) have used a 400-600 micron mesh size to collect stream invertebrates. In multiple habitat sampling, however, this is often supplemented with a smaller mesh size (200 - 300 micron) aimed at the collection of Chironomidae and other small invertebrates. Generally, the smaller the mesh size, the smaller the area of substrate that may be sampled.

Rapid bioassessment programs require relatively versatile collecting gear; equipment that can be used across a wide range of depths, velocities, and substrate types. This decision tends to favor large kick nets and "sweep" nets (D-frame nets, A-frame nets, and dip nets). This type of equipment collects large composite samples, often covering a range of microhabitats. Such composite samples are intended to reduce the variability inherent in small-scale samples. Small-scale (microhabitat) differences in current, canopy, substrate, etc., should not be allowed to obscure between-site changes in water quality. When samples from specific substrates are desired, Hess and Surber samplers are widely used.

Some agencies supplement collections of larvae with sampling of adults (light traps, sweeps) or chironomid pupal exuviae. Given the necessary taxonomic skills, such collections are useful in assigning species names. In high quality areas, it may be very important to document the presence of rare species, or new species.

Visual collections are very important for a complete census of the macroinvertebrate community. Simple disturbance samplers may entirely miss some of the dominant taxa: tightly attached genera (e.g., *Psychomyia*), stone-cased Trichoptera, cryptic genera (e.g., *Nyctiophylax*), or those limited to special microhabitats. There will always be some taxa that will only be found on the largest logs or largest boulders in the stream. Visual collections may be the most important type of collection in large and slow-flowing rivers. This type of collection is the most difficult; experienced collectors will always get more taxa than novices. Therefore, this is an important area on which to focus training efforts.

Level of sampling intensity

Some rapid bioassessment programs establish a variety of sampling methods; the particular method selected is determined by the survey objectives. Plafkin et al. (1989) established three levels of sampling intensity for invertebrates: Rapid Bioassessment Protocols I, II, and III. Protocol I (reconnaissance survey) is intended to document the existence of obvious water quality impairment; it also may be used to see if more detailed studies are required. In this protocol, multiple-habitat collections of invertebrates (field identifications) are conducted by an experienced biologist. It is expected that this process would only require 1 to 2 hours per site with a single investigator. Protocol II uses a 100-count organism subsample from two composited kick-net collections, plus a coarse particulate organic material (CPOM) sample. Organisms are identified in the field to a family level. Protocol II data can be used for site rankings, and requires about 1.5 to 2.5 hours per site with one biologist and one technician. Protocol III uses a similar sampling strategy, but organisms are identified in the lab to the genus/species level.

The idea of different levels of sampling intensity has been adopted by a number of state agencies. Both New York and Ohio have quantitative and qualitative sampling options. North Carolina may use up to three levels of sampling intensity, although only two of these methods have been rigorously tested. Genus/species level-identification is used for all these collection methods, and all samples are field-picked. North Carolina's standard semi-quantitative collections (10 samples) requires 4.5 to 6 person-hours at each site, usually using a three-person collecting team. A more rapid survey (3 person-hours per site) can be achieved using a four-sample collection, limited to EPT taxa. In this sytem, the more rapid methods are subsamples of the standard collection method. The system has been set up so that all stations may be compared, even if different collection methods have been used. Such comparisons are based on regression equations that predict 10-sample EPT taxa richness from the four-sample collections (Eaton and Lenat 1991).

Data Analysis: Metrics

Rapid bioassessment analyses frequently rely on several different ways of examining and summarizing macroinvertebrate data. This use of

multiple metrics originates with the Index of Biotic Integrity used with fisheries information. Just as the IBI had to be modified for regional differences, so must invertebrate indices be retested and adapted for different geographic areas. Some analysis metrics also may vary with flow, season, and ecoregion; and they may not be linear over the entire range of water quality. For example, total taxa richness may increase with moderate enrichment, due to increases in facultative and tolerant groups.

Metrics may be evaluated by either a percent change (versus a reference site) or as a category variable (poor, fair, good, etc.). Categorization is more difficult to establish, as it implies comparisons with a large amount of information from ecoregion reference sites. A "percent change" analysis must take into account both differences due to water quality and the inherent variability of invertebrate communities. There may be a 20 - 30% difference between replicates from identical habitats (c.f. Shackleford 1988), so this level of change can be established as "no impact". Slight-moderate impact usually falls into the range of 30 - 50% change, while severe impact is often established by changes greater than 50%. The exact percentages used to define impact need to be tested for each metric, stream size, stream type, ecoregion, and collection method.

Many agencies rely heavily on paired stations (examples: Arkansas and Maine). This kind of approach automatically adjusts for some temporal changes (especially normal seasonal changes), but control sites must be carefully established to compensate for normal spatial changes. Look carefully at metrics that define any change (versus reference) as stress. For example, do not confuse natural longitudinal changes in the stream community (Hynes 1972) with changes in water quality.

It is difficult to statistically evaluate most rapid bioassessment results if no replicates are taken. Method testing can generate information on the normal variance of any metric, and such tests are important in order to establish the validity of rapid bioassessment data. When data are generated for certain subcategories (usually orders of aquatic insects), it is possible to statistically compare sites with a chi-square analysis or a Wilcoxon signed-rank test. Parrish and Wagner's (1983) modification of the chi-square statistic also has potential for testing between-site differences, but has not yet been widely tested.

The discussion of analysis metrics given below utilizes information from many sources, especially Resh and Jackson (1993).

Structure metrics

Metrics in this category usually can accommodate qualitative or quantitative data; they include taxa richness (number of species, S) analyses, and similarity coefficients. The most commonly used richness metrics are total taxa richness and EPT (Ephemeropta + Plecoptera + Trichoptera) taxa richness. Ohio biologists use the number of mayfly species and the number of caddisfly species as separate metrics. For large studies, the number of "unique" species (limited to single site, with tolerant species excluded) has proved useful (Crawford and Lenat 1989) for comparing sites, although this metric is not suitable for assigning water quality ratings.

EPT taxa richness is the single most reliable metric used by North Carolina biologists. EPT taxa richness was very sensitive to changes in water quality, and it proved to be less variable than total taxa richness in relation to between-year changes in flow (unpublished data from North Carolina's ambient monitoring network).

Simple taxa richness metrics may not always demonstrate impact if drift specimens can easily colonize a stressed site. To deal with this problem, North Carolina uses an "EPT abundance" metric, which is the sum of abundance values (1=rare, 3=common, 10=abundant) for all EPT taxa. This metric responds to a combination of both taxa richness and the relative abundance of the more intolerant groups. Examination of taxa richness data also must take into consideration sources of normal variation, including:

1) Increases (especially for total taxa richness) with mild enrichment.
2) Decreases in nutrient-poor water, especially for single-habitat or subsampled collections. Species accumulation curves may be flatter in such habitats, but intensive, multiple-habitat samples can be used to demonstrate high taxa richness.
3) Seasonal changes, especially taxa richness increases during recruitment periods. Spring peaks are particularly troublesome in the southeastern United States. Limited experiments by North Carolina biologists suggest that seasonal patterns in small streams differ from those in large streams.

4) Effects of stream size, especially decreases in smaller streams. Taxa richness also may decrease in larger rivers, largely as a function of current speed. It is extremely difficult to assign reliable bioclassification to rivers that are transitional between lotic and lentic habitats.

Similarity coefficients are commonly combined with paired-site surveys in order to detect water quality problems. These metrics are useful for identifying compositional changes in the invertebrate community that may not be evident in taxa richness metrics. Resh and Jackson (in press) have reviewed some of the more common similarity coefficients, indicating that suitable equations exist for both qualitative data (e.g., Jaccard Index) or quantitative data (Pinkham-Pearson Index). Maine biologists have had success using a Community Loss Index (Courtemanch and Davies 1987), and this index also has been used for EPA's Rapid Bioassessment Protocols (Plafkin et al. 1989). However, subsequent analyses (Barbour et al, 1992) have shown the Community Loss Index to be highly variable among relatively unimpacted sites. Arkansas (Shackleford 1988) uses both a Common Taxa Index (CTI) and a Common Dominants Index (CDI), and have published classification criteria (versus reference) to define slight, moderate and severe impacts. North Carolina also uses the Arkansas system, modifying the CDI to include all "abundant" taxa.

Community balance

Community balance metrics need some measure of abundance (or relative abundance) and may not be used with presence/absence data. These metrics attempt to measure the evenness (i.e., redundancy) of the invertebrate community, assuming that a highly redundant community (with few species dominating) is evidence of stress. Most ecologists now prefer to examine taxa richness and evenness separately, rather than combine them into a diversity index (Godfrey 1978, Hughes 1978). Florida and Ohio, however, continue to use the Shannon diversity index.

Many mathematical formulas can be used to compute evenness (Peet 1975), but most rapid bioassessment programs prefer very simple calculations. The simplest number is the percent contribution of the dominant (most abundant) taxon (Plafkin et al. 1989). Other biological

monitoring groups look at the percent contribution of some tolerant or intolerant group:

1) EPT abundance/Total abundance
2) EPT abundance/Chironomid abundance (Plafkin et al. 1989, also see Shackleford's (1988) modification of this metric)
3) Hydropsychidae abundance/Total Trichopera, Baetidae abundance/Total Ephemeroptera (Barbour et al., 1992)
4) Tanytarsini abundance/Total Chironomidae expressed as a percentage (Ohio)
5) Maine uses the abundance (or log abundance) of key groups, including Ephemeroptera, *Hydropysche, Cheumatopsyche*, Polycentropidae, Hydropsychidae, *Brachycentrus*, Perlidae, Tanypodinae, and *Rheotanytarsus*.

These metrics must be used with extreme caution, due to *large* differences that may occur between ecoregions, stream sizes, flow conditions, and seasons. In particular, the abundance of Chironomidae at stressed sites can be highly variable (i.e., dominant during low flow, but sharply reduced by scour at high flow). Barbour et al. (1992) recommends deleting the EPT abundance/Chironomidae abundance metric. Community balance metrics may also be influenced by mesh sizes, especially if they include some estimate of chironomid abundance.

Tolerance metrics

Tolerance metrics assume the presence of a large data base, with some pollution tolerance rating assigned to each species. At the lowest level of discrimination, organisms are simply categorized as intolerant, facultative, or tolerant. These categories are then used to compute the percent of intolerant species, based either on taxa richness or abundance.

More precise categorization of water pollution tolerance is needed to compute a biotic index. In North America, most biotic indices are based on Chutter's (1972) system as modified by Hilsenhoff (1982). Hilsenhoff used a large Wisconsin data base (2000+ collections) to assign tolerance values (integer values from 0–5; this was later expanded to a 0–10 range). Recently, a similar attempt was made to derive tolerance values from a large North Carolina data base (Lenat, 1993a). While each list of

tolerance values should show the same overall patterns, there will be many regional differences. For example, many of the southeastern species would not be on a Wisconsin list, and a population in North Carolina may prove to be more or less tolerant than a Wisconsin population.

The presence of deformities also falls into the category of "tolerance metrics". While such analyses are an integral of fish Index of Biological Integrity (IBI) surveys, they are not frequently used for macroinvertebrates. The exception is some excellent work on morphological deformities in chironomid larvae (Warwick 1988, Warwick and Tisdale 1988). Preliminary observation of this concept in North Carolina indicated that it is an excellent (and quick) way to separate the effects of organic pollution from added toxic stress, especially at sites dominated by *Chironomus* larvae (Lenat 1993b).

Feeding group metrics

Feeding group metrics are an outgrowth of river continuum theory (Vannote et al. 1980). This theory predicts that energy flow (and therefore feeding types) should change in a predictable fashion from small streams to large streams. Specifically, the proportion of the invertebrate community that is represented by any given functional feeding group should be predictable from some measure of stream size. Any change in the proportions of the various feeding groups (versus a control site) may indicate water quality problems, but it is important not to equate all such changes with a decline in water quality. This type of water quality analysis requires quantitative data.

Advantages of this approach include the ease of sample collection (the CPOM sample of Plafkin et al. 1989) and the possibility of assigning feeding categories in the field (Cummins and Wilzbach 1985, Cummins 1993). The disadvantages of this approach relate to the difficulty of assigning feeding categories (Resh and Jackson, 1993). It is difficult to assign feeding types to groups which are poorly known or poorly identified. For example, Chironomidae are frequently left at a family level, but many include predators, filter-feeders, collector-gatherers, shredders, and grazers. Many taxa are flexible in their feeding strategies and the same species may have significant between-stream and between-season changes in diet (Chapman and Demory 1963, Kawecka 1977). Comprehensive investigations of feeding habits of Wisconsin Plecoptera,

Ephemeroptera and Trichoptera (Shapas and Hilsenhoff 1976) have pointed out the difficulty of correctly predicting feeding strategies solely from literature reviews. These investigators found that even some species in the same genus had completely different diets. Some taxa also may shift feeding strategies as they grow older (Anderson and Cummins 1979), with some Plecoptera and Trichoptera switching from algal/detrital diets to animal diets in later larval stages. At this time, there is little published information to indicate whether these complicating factors are a major or minor problem in the evaluation of stream water quality.

Feeding groups are usually examined through ratios: shredders/total abundance, scrapers/filterer-gatherers, specialists/generalists (Maine). Initial tests of the first two metrics suggest that they work better when expressed as a percentage, rather than as simple ratio (Barbour et al.). Shackleford (1988) also suggests comparing the proportional makeup of paired sites with a similarity index. The shredder ratio should work well in areas where the shredder guild is relatively abundant at the control site. This restriction will limit its use in the warmer and/or drier portions of the United States. Resh and Jackson found that only the scraper ratio detected water quality changes in the "Mediterranean" climate of northern California. As expected, they also noted sharp seasonal changes in feeding group metrics.

Feeding group metrics will show any change in the proportional composition of feeding types as "stress". Investigators should look for any other habitat changes that might affect food resources in the stream, including changes in riparian vegetation, substrate, and canopy cover.

Special Problems

There are a number of situations that may create special difficulties in the interpretation of rapid bioassessment data. These difficulties, however, are not unique to rapid bioassessment, but will apply to almost any type of chemical and biological sampling. Problems arise when criteria are applied to streams that do not correspond with the data base used to develop these criteria. If your reference sites include a full range of ecoregions, stream sizes, and seasons, these problems are reduced. Few agencies, however, have developed their reference sites to this extent, and these special situations must be examined cautiously.

Small streams

Invertebrate taxa richness in small streams may be limited by low flow (even drying up), lower habitat diversity, and greater thermal constancy (Vannote and Sweeney 1980). Ecoregions with poorly drained or desert soils are especially susceptible to low flow during droughts. North Carolina investigations (unpublished data) indicate that small streams (less than 3 meters wide) have expected EPT taxa richness that are at least 20% lower than larger streams. If it is not possible to adjust taxa richness values from smaller streams, use of tolerance metrics may be a better method of water quality evaluation.

Atypical lotic habitats

Atypical lotic habitats must always be carefully evaluated, including areas below dams, habitats with low current velocity, springs, and swamps. Larger rivers may be difficult to evaluate because of reduced current speed and the problems of finding a comparable unstressed reference station.

Season

Seasonal changes in the macroinvertebrate fauna are a major headache for routine water quality monitoring. Almost any metric may vary seasonally (in the absence of any pollution), and the expected amount of seasonal change may be different for each year (warm versus cold years), ecoregion, and stream size. When possible, periods of rapid changes should be avoided, especially major recruitment periods. If this is not possible, some adjustment must be made to summarize statistics by comparison to reference site data. North Carolina metrics are based on collections during the summer months; these metrics may be used with little adjustment from June to September. Outside of this period, especially in spring, it is often necessary to resample a reference site to assess the degree of seasonal change. In surveys of large catchments, it is advisable to separately assess seasonal changes for streams of different sizes. Ohio and Maine also have established "optimal" months for sampling invertebrates.

North Carolina DEM biologists have experimented with several ways of seasonally adjusting taxa richness values (Trish MacPherson, unpublished data). An equal proportional adjustment at all sites has not worked, as highly stressed sites often had less seasonal change than control sites. Instead, North Carolina biologists are experimenting with "subtraction" methods, where certain species with short life cycles (especially spring species) are deleted before applying taxa richness criteria. Changes in the Plecoptera assemblage are the largest problem in North Carolina, but Ephemeroptera taxa richness also may have sharp seasonal peaks. Seasonal adjustment methods (which differ according to month and ecoregion) must be tested by their success in predicting summer taxa richness at reference sites.

Biotic index values also vary seasonally. Hilsenhoff based his biotic index criteria on spring sampling; he recommends subtracting 0.5 (for a 0–10 scale) for periods "when biotic index values are abnormally high" (i.e., summer) (Hilsenhoff 1988b). North Carolina biotic index criteria (Lenat 1993a) are based on summer sampling. Recommended seasonal adjustments to winter/spring sample, were +0.2 for piedmont and coastal plain areas and +0.5 for mountain areas. (0–10 scale).

Appropriate Use of Rapid Bioassessment Methods

The shortcuts used in rapid bioassessment methods may be associated with either greater data variability or a reduced ability to detect water quality problems. For certain problem situations, one may wish to switch to more intensive methods.

Upstream-downstream studies

Almost any rapid bioassessment method will identify severe impact in a typical "upstream-downstream" survey. A comparison of paired sites allows the use of many different kinds of metrics. More subtle impacts, however, may not be detected with family-level identifications or 100-count samples.

Basin-wide studies

Basin-wide studies (with a range of stream sizes and habitats). This type of survey may be difficult to establish with paired sites, although USGS basin-wide studies are set up in this manner (Gurtz 1994). No direct comparisons should be made betweens streams of different sizes, and normal longitudinal changes should not be interpreted as water quality problems. A cautious use of similarity indices, feeding group metrics, etc., is suggested. North Carolina biologists often utilize a mixture of sampling methods in large basin-wide surveys: EPT surveys in tributaries and full-scale qualitative surveys at key mainstream sites. Preliminary reconnaissance sampling may be useful in establishing a final study plan.

Trend studies

Looking at changes over time ("before-and-after" surveys, trend monitoring sites) requires the best quality data. Only precise taxonomy and complete sampling will be able to detect subtle changes; some rapid bioassessment methods may be inappropriate for ambient monitoring networks. It can be very difficult to separate the effects of between-year changes in flow from actual changes in water quality.

Conservation biology

There is an increasing use of macroinvertebrate studies to identify special "Outstanding Resource Waters" and other high quality aquatic habitats. North Carolina's Bioassessment Group may expend up to one-third of its total efforts in this type of survey. European authors (Jenkins et al. 1984) refer to such sampling as "conservation biology". Conservation biology requires precise taxonomy (species-level where possible); supplemental collections of adults also will improve the reliability of identifications. Both verification of high diversity and identification of rare species are important components of conservation biology. For this reason neither subsampling nor family-level identifications are appropriate survey techniques.

Examples

EPA (1991) compiled a summary of bioassessment programs and biological criteria in Arkansas, Florida, North Carolina, Maine, and Ohio. Case studies also were presented from Connecticut, Delaware, Minnesota, Nebraska, New York, Texas, and Vermont. Only two examples are given here, representing two contrasting styles of rapid bioassessment: North Carolina's multiple-habitat samples and the EPA single habitat approach using a 100-organism subsample.

North Carolina

The North Carolina examples are drawn from a large study of discharger toxicity (Table 11.1). We have selected two surveys indicating a toxic impact on stream fauna and two surveys indicating no significant impact. Sites are rated with taxa richness criteria and a biotic index; these metrics are evaluated against ecoregion expectations. Paired-site metrics also are employed here: a Common Dominants Index, a Common Taxa Index and a Wilcoxon Signed Rank test. All data are in an ordinal scale (absent=0, rare=1, common=—3, abundant=10), which precludes the use of evenness measures or feeding group metrics.

Of the two studies with an apparent impact, only one developed tolerant "indicator" assemblages; only in this study was there a change in biotic index values and a large change in community composition. The similarity measures may be overly sensitive; they sometimes indicated "slight impact" even when there appeared to be no significant change in water quality.

Of the four studies, two were in agreement with the effects predicted by water chemistry and standard toxicity tests. The other two studies, however, produced unexpected results. Discharger B was in compliance with chemical permit limits and was passing *Ceriodaphnia* chronic toxicity tests. Conversely, Discharger D was failing their toxicity tests, but did not appear to be affecting stream biota. This information clearly indicated that rapid bioassessment methods are often better than water chemistry or toxicity tests in detecting water quality problems.

Table 11.1. Examples of information from North Carolina's standardized qualitative collection method: taxa richness by group, and summary statistics. Four "upstream/downstream" studies of wastewater treatement plants, two surveys indicating impact vs. two surveys indicating no impact. All data collected September 1990.

Station	With Impact				No Impact			
	A1	A2	B1	B2	C1	C2	D1	D2
Group								
Ephemeroptera	6	1	8	1	11	10	7	7
Plecoptera	3	0	0	0	3	4	2	3
Trichoptera	6	5	5	3	8	7	6	8
Coleoptera	2	3	3	3	6	7	6	8
Odonata	3	5	6	7	5	6	8	10
Megaloptera	2	2	1	2	1	3	2	2
Diptera: Misc.	4	5	5	1	6	4	3	3
Diptera: Chironomidae	22	17	19	7	25	25	27	22
Oligochaeta	2	2	3	2	1	3	4	5
Crustacea	1	1	1	1	1	2	2	4
Mollusca	0	0	1	0	2	1	2	3
Other	1	0	0	0	0	0	3	4
EPT Taxa Richness	12	6	13	4	22	21	15	18
EPT Abundance	52	28	59	4	127	100	88	102
Total Taxa Richness	50	40	52	27	69	72	72	80
Taxa Richness Rating	Fair	Poor	Fair	Poor	G-F	G-F	Fair	G-F
Biotic Index (1-5 scale)	3.49	3.53	3.24	3.88*	2.95	3.06	3.10	2.93
	Fair	Fair	G-F	Poor	G-F	G-F	G/F	G/F
Indicator Assemblages								
Organics/Enrichment	-	+	-	-	-	-	+	-
Toxics	-	-	-	++	-	-	-	++
Between-site Tests								
Common Taxa	44% (Mod)		29% (Severe)		76% (None)		63% (Slight)	
Common Dominants**	50% (Mod)		8% (Severe)		76% (Slight)		68% (Slight)	
Wilcoxon Signed Rank	NS		Significant		NS		NS	
Impact?	Yes		Yes		No		No	
Agreement with Chemistry and Toxicity data?	Yes		No		Yes		No	

*Between-site difference >0.5, significant change in water quality, bioclassifications based on biotic index numbers are tentative. Scale = 0.5
**Dominants defined as any abundant taxa (≥10 specimens/site).
***GF = Good-Fair

EPA Protocol III example

Example data sets are presented from four of the EPA rapid bioassessment workshops (Table 11.2). Both nonpoint source problems and point source discharges were included in these test cases. Two surveys were selected that indicated slight impact (Kansas and Texas), while two other surveys indicated moderate impact (Massachusetts and District of Columbia). Impact assessment followed the procedures outlined in Plafkin et al. (1989).

Table 11.2. Examples of data using EPA's rapid Bioassessment Protocol III, 100-count samples. Information from four rapid bioassessment workshops, 1990[1]. Values are relative abundance (percent of total).

	Slight Impact				Moderate Impact			
	A1	A2	B1	B2	C1	C2	D1	D2
Group								
Ephemeroptera	19	35	35	17	4	1	47	4
Plecoptera	0	0	21	11	4	0	26	0
Trichoptera	0	11	2	3	4	0	28	1
Coleoptera	11	23	10	2	2	0	0	0
Megaloptera	0	0	0	0	1	0	2	2
Diptera: Misc.	2	14	24	3	13	0	6	5
Diptera: Chironomidae	8	18	10	48	74	7	8	85
Oligochaeta	10	0	0	3	0	3	0	0
Crustacea	23	3	0	2	1	63	0	0
Mollusca	25	2	0	5	5	4	3	3
Other	2	0	0	1	0	7	2	17
Selected Metrics								
Total Taxa Richness	16	14	12	17	25	11	21	26
EPT Taxa Richness	3	2	5	5	8	1	11	2
HBI[2]	6.54	5.94	6.86	8.66	4.98	7.59	4.29	6.31
Scrapers/Filterers	1.13	0	0.22	0.07	0.02	0	0.30	0
Between-site Tests	65% (Slight)		75% (Slight)		42% (Moderate)		30% (Moderate)	

[1]A: Upstream/downstream of WWTP (Kansas), B: Nonpoint source problem (Texas), C: Upstream/downstream of WWTP and paper mill (Massachusetts), D: Nonpoint source problem (Washington, D.C.)
[2]Hilsenhoff Biotic Index, based on tolerance range of 0-10, adjusted to include non-arthropods.

These data suggest that relying solely on traditional metrics (taxa richness, Hilsenhoff Biotic Index) may not be sufficient to deduce the health of aquatic communities. In the first two data sets (slight impact), most metric values did not differ substantially between sites. Information on abundance by taxonomic group, however, was more indicative of between-site differences, producing overall between-site comparisons of 65 – 75%. For sites with moderate impact, the EPT index was the most informative metric, while total taxa richness showed between-site differences for only one of these examples. Overall between-site comparisons for these two examples were in the range of 30 – 42%.

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Terrestrial Activity, Abundance and Species Richness of Amphibians in Managed Forests in South Carolina

HUGH G. HANLIN[1]

Department of Biology and Geology, University of South Carolina, Aiken 29801

F. DOUGLAS MARTIN

Savannah River Technology Center, Westinghouse Savannah River Company, Building 773-42A, Aiken, South Carolina 29808

LYNN D. WIKE

Savannah River Technology Center, Westinghouse Savannah River Company, Building 773-42A, Aiken, South Carolina 29808 and Department of Biology and Geology, University of South Carolina, Aiken 29801

AND

STEPHEN H. BENNETT

South Carolina Wildlife & Marine Resources Department, Nongame and Heritage Program, P.O. Box 167, 1000 Assembly Street, Columbia 29202

ABSTRACT.—We determined the relative abundance, days of surface activity and indices of species diversity, evenness and richness for amphibians inhabiting three differently managed forests surrounding a Carolina bay in South Carolina following restoration. We collected animals daily for 3 y (Oct. 1993–Sept. 1996) using drift fences with pitfall traps in three forest types: loblolly pine (*Pinus taeda*), slash pine (*P. elliotti*) and mixed hardwoods (predominantly oak, *Quercus* spp. and hickory, *Carya* spp.). Captured animals were marked and recaptures were recorded but not included in statistical analyses, except in our evaluation of activity. We compared results to those of a more limited study conducted before restoration.

Amphibians were significantly more numerous and more active in the mixed hardwood forest than in the pine forest types. However, the hardwood forest had the lowest species diversity in 2 of the 3 y of the study. The slash pine habitat had the highest diversity in all 3 y and for the 3 y combined. Because the evenness index (J′) values differ in step with the species diversity index (H′) it appears that the evenness component of diversity, rather than the richness component, is what is determining H′ variation. A summer subset of these data and summer data from an earlier study of 1977–1978 is in marked contrast with yearlong patterns. For our summer data each forest type had the highest H′ value in one of the years of the study and again the J′ values parallel the differences in H′.

Large numbers of southern toads (*Bufo terrestris*) reduced evenness, and therefore species diversity, for all three habitats particularly the mixed hardwoods where this species was especially abundant. Proportionally lower numbers of *B. terrestris* in the summer samples increased J′ and H′ indices. Overall lower abundance and H′ values in the summers of 1994–1996 compared with 1977–1978 may be the result of habitat alteration during the restoration of the Carolina bay.

INTRODUCTION

In recent years forest management practices of the forest products industry have received close scrutiny. The industry faces the challenge of developing management plans that op-

[1] Corresponding author: Telephone (803) 641-3439; FAX (803) 641-3251; e-mail: hughh@aiken.sc.edu

timize the production of timber while maintaining environmental quality, including the functional integrity of wildlife habitats (Sharitz *et al.*, 1992; Siegel, 1995).

For over 40 y, thousands of acres of the Savannah River Site near Aiken, South Carolina, have been managed by the United States Forest Service for production of pulpwood by harvesting planted pine plantations. Many of these managed forests are contiguous with Carolina bays, natural wetlands unique to the southeastern Atlantic Coastal Plain (Schalles *et al.*, 1989). In addition to providing forage and water for upland wildlife, Carolina bays are particularly important sites for amphibian reproduction and larval development (Patterson, 1978; Sharitz and Gibbons, 1982; Pechmann *et al.*, 1989). At least 34 species of amphibians have been reported from Carolina bays on the Savannah River Site (Schalles *et al.*, 1989; Gibbons and Semlitsch, 1991); 31 of these are terrestrial for a portion of their life cycle. Therefore, alteration of terrestrial habitats, particularly those contiguous with these natural wetlands, may affect the life histories of the amphibian species. Amphibians have often been neglected when evaluating the impacts of forest management practices on wildlife (Bury *et al.*,1980; Bury, 1988; Wigley and Roberts, 1994), in spite of their vital position in forest food webs (Burton and Likens, 1975; Vitt *et al.*, 1990), their value as indicators of habitat quality (Bury and Corn, 1988; Gibbons, 1988; Wake, 1991; Dunson *et al.*, 1992) and endangered biodiversity (Dobson *et al.*, 1997) and their apparent declining global populations (Blaustein and Wake, 1990). However, interest in the relationships of amphibian ecology and management practices is increasing (deMaynardier and Hunter, 1995).

Lost Lake, a Carolina bay located on the Savannah River Site, was ditched and drained for agricultural production from before 1943 until the early 1950s. After the Atomic Energy Commission removed the land from farming the cultivated area around the bay was planted in single-species stands of loblolly pine (*Pinus taeda*) in 1952 and slash pine (*P. elliotti*) in 1953. An uncultivated area remained in mature mixed deciduous hardwood species, primarily oak (*Quercus* spp.) and hickory (*Carya* spp.). The bay was allowed to refill and function as a wetland, although overflow from a settling basin for a nearby industrial complex contaminated the bay with a variety of pollutants, primarily cleaning fluids, solvents and heavy metals.

Based on aerial photographs from the late 1930s, the hardwood forest is more than 60 y old. The two pine forests surrounding Lost Lake have routinely been burned since their planting 45 y ago, the two most recent treatments occurring in 1980 and 1986. Prescribed burning reduces leaf litter, woody debris and shrubs in the understory. The relationship of forest habitat to the abundance and distribution of amphibians has been shown to vary with the amount of coarse woody debris (Welsh and Lind, 1991; Petranka *et al.*, 1994), leaf litter depth and type (Pough *et al.*, 1987; Corn and Bury, 1991), humus/soil acidity (Wyman and Jancola, 1992) and hardwood shrub abundance (Pough *et al.*, 1987; Raphael, 1988). These habitat features are directly influenced by stand age, tree species composition and management practices (DeGraaf and Rudis, 1990; Grant *et al.*, 1994; Dupuis *et al.*, 1995).

In 1977–1978 Bennett *et al.* (1980) conducted one of the earliest examinations of the relationship of forestry practice and amphibian community structure at Lost Lake. Their study was designed to determine terrestrial activity, relative abundance and diversity of amphibians in the three forest types contiguous to the wetland which, because of pollution, no longer supported either emergent or submerged aquatic macrophytes. The forests were sampled from 30 June–10 Aug. 1977 and from 20 June–15 Aug. 1978. Bennett *et al.* reported that the three forests were similar in species diversity reported as H′ for combined summer data and for the summer of 1978. The hardwood forest was reported to have a higher

diversity in 1977. The hardwood forest also yielded approximately 50% more individual amphibians than either pine forest during both years.

In 1990 a closure plan for the settling basin near Lost Lake was developed which included, in addition to closing the basin, the restoration of the degraded Carolina bay to a "natural wetland system" (Gladden *et al.*, 1992). The surrounding forest within a minimum radius of 50 m was removed and the bay was drained. All vegetation from the removal action was burned and the residual ash and contaminated sediments were moved to the settling basin and compacted. After replacement of removed sediments with "clean" soil the bay was allowed to refill and aquatic vegetation was planted. Before restoration Lost Lake had a surface area of approximately 2 ha (Schalles *et al.*, 1989). Based on a 1996 aerial photograph the current surface area is approximately 6.5 ha.

Since 1993 we have studied the amphibians and their colonization of Lost Lake in an effort to assess the success of restoration. Because the amphibian populations colonizing the wetland inhabit or migrate through the three adjacent forests, we were also able to reevaluate the relative abundance, diversity and fluctuations of the populations in each of the three forests and to compare our results with prerestoration data (Bennett *et al.*, 1980).

METHODS

Study site.—The dominant aquatic plants in Lost Lake are cattail (*Typha latifolia*) and floating heart (*Nymphoides cordata*) which are unevenly distributed in the littoral zone. Based on the wetland vegetation indicator categories presented by Reed (1988), the dominant vegetation in the previously cleared perimeter area is nonplanted facultative wetland, facultative upland and obligate upland herbaceous species often associated with "old field" habitats (Ornes *et al.*, 1996; W. Harold Ornes, pers. comm.). Blackberry (*Rubus* spp.) and woody shrubs, primarily southern bayberry (*Myrica cerifera*), increase in density at the edges of the surrounding forests. The estimated areas of the three forest types in the immediate vicinity of Lost Lake are 16.4 ha of loblolly pine, 17.0 ha of slash pine and 3.2 ha of mixed hardwoods. The open primarily herbaceous vegetation separating the forests from the wetlands differs markedly from the vegetation before restoration. Bennett *et al.* (1980) reported that the dominant forest type changed along the bay margin so that there was a hardwood-shrub community composed primarily of white oak (*Quercus alba*), mockernut hickory (*Carya tomentosa*) and southern bayberry (*Myrica cerifera*) between the bay and the pine forests and a pine and hardwood-shrub community (predominantly loblolly pine and southern bayberry) between the bay and the mixed hardwood forest. Unpaved service roads now separate each forest type, dissect each of the pine forests and encircle the restored landscape separating it from the surrounding forests.

Population sampling.—We sampled amphibian populations using drift fences with pitfall traps (Gibbons and Semlitsch, 1982), artificial coverboards (Grant *et al.*, 1992; Fellers and Drost, 1994), minnow traps and hand collecting (Scott, 1994). Whereas the latter two methods were used to evaluate species presence or absence, only data collected by drift fences were used for the purpose of comparing amphibian numbers among the three forest types. The reasons for this are that collecting effort can be quantified accurately for this method; skill of field assistants has minimal impact on this method; and we wanted to be able to compare our data with the prerestoration data of Bennet *et al.* (1980) obtained by this method. Drift fences and coverboards were sampled daily for the entire study, whereas minnow traps were deployed only 1 wk per month and sampled daily for that week. Hand capture was as opportunity allowed.

Thirteen 30 m long drift fences were established around Lost Lake and in the surrounding forests. Eight drift fences, the "inner set," were established in the brushy areas 30 m from and parallel to the water's edge. An additional five drift fences, the "outer set," were established 100 m from and parallel to the water's edge and within a forested area. Of these, two of the inner set and one of the outer set of drift fences are not considered further because their placement was not clearly related to a single forest type. Nineteen-liter steel buckets, which functioned as pitfall traps, were sunk to ground level at each end of the drift fence and at 10 m intervals on both sides of the fence. Comparisons to prerestoration data were restricted to the six drift fences that we located closest geographically to the six drift fences used by Bennett *et al.* (1980). These six drift fences included one member from the "inner set" and one from the "outer set" related to each forest type.

Construction of all pitfall traps was completed in September 1993. We checked all traps daily from 1 Oct. 1993 to 30 Sept. 1996. Because regular sampling began on 1 Oct., study years do not correspond to calendar years, but instead run from 1 Oct. to 30 Sept. This was a convenient starting point because it was before the late fall/early winter breeding migrations and after the late summer/early fall emergence of metamorphs. Captured amphibians were toe-clipped (Ferner, 1979), but not for individual recognition, and released. Animals captured along a drift fence were released on the opposite side of the fence. Animals which were, for any reason, difficult to identify were taken into the laboratory for identification and then returned and released. Recaptures were recorded but removed from the data set for all statistical analyses, except in our evaluation of surface activity.

Statistical analyses.—We determined relative abundance of amphibian species and number of days $year^{-1}$ individuals of each species were captured in each forest type and tested differences among habitats using ANOVA. Before analyzing data we decided that surface activity analysis should be restricted to the six species which individually make up 1% or more of the captures for a given year in at least one of the forest types. These six species are mole salamander (*Ambystoma talpoideum*), tiger salamander (*A. tigrinum*), southern toad (*Bufo terrestris*), eastern narrowmouth toad (*Gastrophryne carolinensis*), eastern newt (*Notophthalmus viridescens*) and southern leopard frog (*Rana utricularia*).

We calculated the species diversity index, H' (Shannon, 1948), the species evenness index, J' (Pielou, 1969) and the species richness index, R_1 (Margalef, 1958) and compared among habitats and study years. These indices were chosen in order to directly compare these data with previous studies. Calculations were performed using natural logarithms (base e). The *t*-test (Brower *et al.*, 1990) was employed to compare H' values among forest types and among years. Annual data were based on the time period of 1 Oct.–30 Sept., and the study year designation (*e.g.*, 1994) refers to the year in which most of the sampling period fell. When we made comparisons to prerestoration data, the summer subset of data for 1994 through 1996 was the time period 30 June–15 Aug. which incorporated the starting date of the 1977 data and the ending date of the 1978 data.

The prerestoration data of Bennett *et al.* (1980) was presented in their publication with the diversity indices calculated using logarithmic base 2. For the purposes of comparison to our data, prerestoration indices were recalculated using natural logarithms. We used the *t*-test to compare among forest types for 1978 but, because data were available only in summary form for 1977, we were unable to test the 1977 diversity indices.

RESULTS

During the 3 y of our study we captured 40,119 amphibians of 19 species. All 19 species were taken in the oak-hickory forest whereas 18 were taken in each of the other two (Table 1). One species taken in the hardwood forest, the green frog (*Rana clamitans*), was represented by a single specimen. The southern toad (*Bufo terrestris*) was the numerically dominant species in all habitats, representing approximately 74% of captures. One other

TABLE 1.—Numbers of species and individuals and indices of diversity (H'), evenness (J') and richness (R_1) of amphibians in different forest types adjacent to Lost Lake, Savannah River Site, South Carolina

Sampling period	Forest type	# Species	# Individuals	Mean #/ fence	H'	J'	R_1
Oct. 1993–Sept. 1994	Hardwood	14	5751	1917.0	0.92	0.34	1.50
	Loblolly	17	3501	875.2	1.14	0.40	1.96
	Slash	15	2452	817.3	1.15	0.42	1.79
	Combined	18	11,704	1170.4	0.98	0.34	1.86
Oct. 1994–Sept. 1995	Hardwood	17	7711	2570.3	0.85	0.29	1.79
	Loblolly	18	9286	2321.5	0.53	0.18	1.86
	Slash	14	3144	1048.0	1.09	0.41	1.61
	Combined	19	20,141	2014.1	0.76	0.26	1.82
Oct. 1995–Sept. 1996	Hardwood	15	5277	1759.0	0.78	0.30	1.52
	Loblolly	12	1968	492.0	1.01	0.38	1.71
	Slash	12	1029	343.0	1.19	0.48	1.58
	Combined	15	8274	827.4	0.91	0.34	1.55
Oct. 1993–Sept. 1996	Hardwood	19	18,739	6246.3	0.90	0.30	1.83
	Loblolly	18	14,755	3688.8	0.84	0.29	1.77
	Slash	18	6625	2208.3	1.18	0.43	1.70
	Combined	19	40,119	4011.9	0.94	0.32	1.71

frog species, the eastern narrowmouth toad (*Gastrophryne carolinensis*), and two salamanders, the eastern newt (*Notophthalmus viridescens*) and the mole salamander (*Ambystoma talpoideum*), were also well represented. These four species together account for approximately 98% of all amphibians captured.

There were significant differences in amphibian abundance and diversity both between forest types and between years within each forest type (Tables 1, 2). The mixed hardwood forest had the highest mean capture rate $fence^{-1}$ $year^{-1}$ for all years. However, the mixed hardwood forest had the lowest H' and J' indices for each of the 3 y and for the pooled sample. The slash pine stand had the highest H' indices for each of the 3 y and for the combined 3 y sample. The *t*-test showed all H' values to be highly significantly different ($P < 0.001$) in comparisons between habitats within each year and for the combined 3 y sample and between years for each habitat. The one exception was the comparison between loblolly and slash pine for study year 1994 which was not significant.

Of the two components of species diversity (evenness and richness), evenness (J') had the larger influence on species diversity values. The hardwood forest had the lowest J' values for each year and for the combined years (Table 1). Slash pine forest J' values were the highest for all three study years and overall. The loblolly pine forest had the highest richness (R_1) values for each year of sampling, whereas the mixed hardwood forest had the highest R_1 value for the 3 y combined.

When capture rates for total numbers of amphibians were compared with forest type, study year and distance of drift fence from Lost Lake, the highest numbers of individuals captured were in the hardwood forest, in study year 1995 for all forest types, and in the drift fences 30 m from the shoreline as compared to 100 m (*see* Tables 3, 4).

Because drift fences with pitfall traps depend on surface movements of individuals for captures, a measure of amphibian terrestrial surface activity can be obtained by determining the number of days $year^{-1}$ that at least one individual of each species was captured in each forest type. Both original captures and recaptures are included in this calculation. This activity value was affected not only by population size but also by climatic conditions and by habitat suitability. Since we can assume comparable general climatic conditions (as opposed to microclimate) among the three forest types during this study, the activity value provides an insight into population availability/habitat suitability of each forest type for each species (*see* Table 5). Based on the results from the ANOVA (Table 6), mole salamanders, southern toads and eastern newts have significantly more days $year^{-1}$ of surface activity in the hardwood forest than in the pine forests. Mole salamanders and eastern narrowmouth toads also had significantly more days $year^{-1}$ of surface activity in 1995 than in the other 2 y. Further, mole salamanders, eastern narrowmouth toads and southern leopard frogs (*Rana utricularia*) showed significantly more days $year^{-1}$ of surface activity at drift fences 30 m from Lost Lake compared to the fences 100 m from the shoreline. No significant interaction among factors (forest type, study year or distance from water) was indicated.

TABLE 2.—Numbers of species and individuals and indices of diversity (H'), evenness (J') and richness (R_1) of amphibians in different forest types adjacent to Lost Lake, Savannah River Site, South Carolina for summer only samples. 1977 and 1978 data from Bennett *et al.* (1980) recalculated using natural logarithms rather than base 2 logarithms

Sampling period	Forest type	# Species	# Individuals	Mean #/ fence	H'	J'	R_1
Summer 1994	Hardwood	9	619	206.3	1.00	0.46	1.24
	Loblolly	10	913	228.2	0.76	0.33	1.32
	Slash	8	409	136.3	0.87	0.42	1.16
	Combined	12	1571	157.1	0.91	0.36	1.49
Summer 1995	Hardwood	7	662	220.7	0.80	0.41	0.92
	Loblolly	7	514	128.5	0.69	0.36	0.96
	Slash	7	101	33.7	1.15	0.59	1.30
	Combined	9	1277	127.7	0.81	0.37	1.12
Summer 1996	Hardwood	6	148	49.3	0.98	0.54	1.00
	Loblolly	5	134	33.5	1.00	0.62	0.82
	Slash	4	85	28.3	0.52	0.38	0.68
	Combined	7	367	36.7	0.95	0.48	1.02
Summers 1994–1996	Hardwood	11	1429	476.3	1.00	0.42	1.38
	Loblolly	13	1561	390.2	0.91	0.35	1.63
	Slash	12	595	198.3	0.95	0.38	1.72
	Combined	13	3215	321.5	1.00	0.39	1.48
Summer 1977	Hardwood	7	1158	579.0	0.99	0.59	0.85
	Loblolly	8	844	422.0	0.70	0.34	1.04
	Slash	6	834	417.0	0.63	0.35	0.74
	Combined	10	2836	472.7	0.83	0.36	1.32
Summer 1978	Hardwood	13	3634	1817.0	1.37	0.53	1.46
	Loblolly	11	2490	1245.0	1.39	0.58	1.28
	Slash	10	3334	1667.0	1.26	0.55	1.56
	Combined	14	8545	1424.2	1.37	0.52	1.44
Summer 1977–1978	Hardwood	14	4792	2396.0	1.41	0.54	1.53
	Loblolly	13	3334	1667.0	1.36	0.53	1.48
	Slash	12	4168	2084.0	1.23	0.50	1.36
	Combined	16	11,381	1896.8	1.37	0.49	1.61

TABLE 3.—Numbers of species and individuals and indices of diversity (H'), evenness (J') and richness (R_1) of amphibians at drift fences 30 m from the edge of Lost Lake compared to drift fences 100 m from the edge of Lost Lake

Distance	Sampling period	# Species	# Individuals	Mean #/fence	H'	J'	R_1
30 m	Oct. 1993–Sept. 1994	15	9496	1582.7	1.00	0.37	1.53
	Oct. 1994–Sept. 1995	18	16,095	2682.5	0.68	0.23	1.65
	Oct. 1995–Sept. 1996	12	6585	1047.5	0.85	0.34	1.59
	Oct. 1993–Sept. 1996	18	32,176	5362.7	0.87	0.30	1.35
100 m	Oct. 1993–Sept. 1994	17	2208	552.0	1.40	0.49	2.08
	Oct. 1994–Sept. 1995	17	4046	1011.5	1.02	0.36	1.68
	Oct. 1995–Sept. 1996	14	1689	422.2	1.09	0.41	1.88
	Oct. 1993–Sept. 1996	19	7943	1985.8	1.24	0.42	1.56

Twelve species were collected during the summers of 1994–1996 (Tables 7, 8). Eastern narrowmouth toad (57%) and southern toad (40%) were the two numerically dominant species, representing 97% of captures. Of 1788 total captures during these sampling periods, 57% of the captures occurred in the oak-hickory forest, 24% in the loblolly forest and 19% in the slash pine forest. Each forest type had the highest H' value in one of each of the summers; in every case the J' values paralleled the differences in H' (Table 2). For the three summers combined the mixed hardwood forest had the highest H' value. Comparisons of species diversity for the three forest types within each year and for the combined 1994–1996 summer data were all significantly different ($P < 0.001$), even when using the Bonferroni adjustment.

DISCUSSION

Drift fences with pitfall traps are commonly used to inventory terrestrial amphibians, but relative abundance of species collected by this method alone must be reported with caution (Corn, 1994). In this study no conclusions can be drawn concerning the relative abundance of different species within each habitat since drift fences and pitfall traps capture some species more easily than others do. However, because species assemblages and sampling methods were similar among the three different habitats and among years, relative abundance is useful in evaluating suitability of each forest type for those species which are easily captured by this method.

TABLE 4.—ANOVA table for the effects of study year, forest type and distance from Lost Lake on annual capture of amphibians by drift fences. Total capture refers to the captures of all amphibians combined within a habitat drift fence^{-1} year^{-1}

Total capture	df	F	P
Forest type (F)	2	5.00	0.03
Study year (Y)	2	4.88	0.03
Distance from Lost Lake (D)	1	14.02	0.003
F × Y	4	0.84	0.53
F × D	2	0.95	0.41
Y × D	2	1.03	0.38
F × Y × D	4	0.69	0.62
Error	12		

TABLE 5.—Days year^{-1} surface activity as measured by drift fence captures for the six species which make up 1% or more of the captures from any given forest type. Recaptures are included in this summary

	Hardwood			Slash pine			Loblolly pine		
	1994	1995	1996	1994	1995	1996	1994	1995	1996
Eastern narrowmouth toad	93	92	63	79	62	45	72	72	48
Southern toad	103	159	103	92	101	59	70	88	81
Eastern newt	60	51	43	23	16	21	44	22	31
Mole salamander	20	55	46	15	44	42	15	35	25
Tiger salamander	10	27	12	7	19	13	10	28	5
Southern leopard frog	8	11	9	8	9	1	1	10	5

Species diversity, as measured by a diversity index, has been used as an indicator of environmental quality, the assumption being that the higher the species diversity within a given habitat the greater the "quality" of that habitat (Magurran, 1988). However, in this study the species diversity index alone does not appear to accurately reflect the relative quality of these forest types for this amphibian community. For example, large numbers of the numerically dominant species, the southern toad, lowered the species evenness index and, therefore, the diversity index values in all three habitats. Since the oak-hickory forest supported greater numbers of this species, the species diversity index for that habitat was proportionally more depressed than were the species diversity indices for the two pine forests. Measures of abundance, surface activity and richness, however, suggest that the mixed hardwood forest provides a more suitable habitat than the managed pine forests for the amphibian community in the Lost Lake watershed. We would caution those responsible for making forest management decisions that using calculated species diversity indices alone in determining habitat suitability for amphibian species may give an inaccurate assessment of habitat quality.

There was considerable contrast between the results of our 3 y sampling program and the results of the summer sampling periods in 1977–1978 (Bennett *et al.*, 1980). In 1978 all species diversity index values were higher than the highest values for comparable subsets of our data for the summers of 1994–1996 (Table 2). Although Bennett *et al.* (1980) reported that the three habitats "were not appreciably different from one another" in diversity, *t*-tests of the recalculated indices for 1978 showed both hardwood and loblolly pine forests to be significantly more diverse than the slash pine forest ($P < 0.02$ and $P < 0.01$, respectively). The hardwood and loblolly forests were not significantly different from each other. Although the differences in diversity index values among forest types for 1977 were greater than those for 1978, the differences could not be tested for significance. When combined for 1977–1978, the oak-hickory habitat showed the highest values of H', J' and R_1, and the slash pine forest showed the lowest values for all three indices. This pattern was duplicated when the summer only data for 1994–1996 were considered. Species diversity for the summers of 1994–1996 were lower than those for the combined 1977–1978 data, but the *t*-test could not be calculated because of inclusion of the 1977 summarized data.

Bennett *et al.* (1980) reported 16 species from Lost Lake in the summers of 1977–1978. Twelve of these species were also collected during the summers of 1994–1996 (Tables 7, 8). Three species collected in 1977–1978 (marbled salamander, *Ambystoma opacum*; green frog,

TABLE 6.—ANOVA table for the effects of study year, forest type and distance from Lost Lake on days of activity year^{-1} for those species which make up one percent or more of the annual captures for any forest type

	df	F	P
Mole salamander			
Forest type (F)	2	9.54	0.003
Study year (Y)	2	37.27	<0.001
Distance from Lost Lake (D)	1	18.47	0.001
F × Y	2	0.58	0.58
F × D	4	1.11	0.40
Y × D	2	1.67	0.23
F × Y × D	4	0.32	0.86
Error	12		
Tiger salamander			
Forest type (F)	2	1.50	0.26
Study year (Y)	2	1.81	0.20
Distance from Lost Lake (D)	1	9.26	0.01
F × Y	2	0.67	0.63
F × D	4	0.31	0.74
Y × D	2	0.57	0.58
F × Y × D	4	0.83	0.53
Error	12		
Southern toad			
Forest type (F)	2	11.63	0.002
Study year (Y)	2	6.20	0.01
Distance from Lost Lake (D)	1	0.21	0.66
F × Y	2	0.76	0.57
F × D	4	1.30	0.31
Y × D	2	3.10	0.08
F × Y × D	4	0.20	0.93
Error	12		
Eastern narrowmouth toad			
Forest type (F)	2	6.30	0.01
Study year (Y)	2	23.50	<0.001
Distance from Lost Lake (D)	1	10.46	0.007
F × Y	2	0.66	0.63
F × D	4	2.10	0.17
Y × D	2	0.36	0.71
F × Y × D	4	0.57	0.69
Error	12		
Eastern newt			
Forest type (F)	2	17.46	<0.001
Study year (Y)	2	3.15	0.08
Distance from Lost Lake (D)	1	9.40	0.01
F × Y	2	0.66	0.64
F × D	4	3.88	0.05
Y × D	2	3.22	0.08
F × Y × D	4	0.36	0.84
Error	12		
Southern leopard frog			
Forest type (F)	2	2.2	0.15
Study year (Y)	2	0.48	0.63
Distance from Lost Lake (D)	1	15.20	0.002
F × Y	2	1.37	0.30
F × D	4	0.34	0.72
Y × D	2	0.18	0.84
F × Y × D	4	0.32	0.86
Error	12		

TABLE 7.—Amphibian species captured during this study and the 1977–1978 study by Bennett *et al.* (1980) listed by study year. Data from Bennett *et al.* (1980) are for summer only while other data are from entire year

Species	1977	1978	1994	1995	1996
Acris gryllus, Southern cricket frog			X	X	X
Ambystoma opacum, Marbled salamander	X	X	X	X	X
Ambystoma talpoideum, Mole salamander		X	X	X	X
Ambystoma tigrinum, Tiger salamander			X	X	X
Bufo quercicus, Oak toad	X		X	X	
Bufo terrestris, Southern toad	X	X	X	X	X
Eurycea quadridigitata, Dwarf salamander		X			
Gastrophryne carolinensis, Eastern narrowmouth toad	X	X	X	X	X
Hyla cinerea, Green treefrog	X	X	X	X	X
Hyla gratiosa, Barking treefrog		X	X	X	X
Hyla squirella, Squirrel treefrog	X		X	X	X
Hyla versicolor/chrysoscelis, Gray treefrog		X		X*	
Notophthalmus viridescens, Eastern newt	X	X	X	X	X
Plethodon glutinosus, sensu latu, Slimy salamander	X	X	X	X	X
Pseudacris crucifer, Spring peeper			X	X	X
Pseudacris nigrita, Southern chorus frog			X	X	
Pseudacris ornata, Ornate chorus frog			X	X	X
Rana catesbeiana, Bullfrog		X	X	X	X
Rana clamitans, Green frog		X		X	
Rana utricularia, Southern leopard frog	X	X	X	X	X
Scaphiopus holbrooki, Eastern spadefoot toad	X	X	X	X	

* Calling male heard, not captured

TABLE 8.—Number of individuals captured during the summer sampling periods for this study and the 1977–1978 study by Bennett *et al.* (1980) totaled by study year

Species	1977	1978	1994	1995	1996	Total captures
Gastrophryne carolinensis, Eastern narrowmouth toad	1984	2211	558	296	122	5171
Bufo terrestris, Southern toad	688	2624	147	463	90	4012
Notophthalmus viridescens, Eastern newt	19	3066	28	6	3	3122
Ambystoma talpoideum, Mole salamander		394	2	22		418
Plethodon glutinosus, sensu latu, Slimy salamander	67	81	1			149
Rana utricularia, Southern leopard frog	1	79			2	82
Scaphiopus holbrooki, Eastern spadefoot toad	70	7				77
Hyla gratiosa, Barking treefrog		58		3		61
Hyla cinerea, Green treefrog	2	1			12	15
Acris gryllus, Southern cricket frog			7	3	3	13
Rana catesbeiana, Bullfrog		6	6			12
Eurycea quadridigitata, Dwarf salamander		10				10
Hyla squirella, Squirrel treefrog	1		7	2		10
Bufo quercicus, Oak toad	3		5			8
Ambystoma opacum, Marbled salamander	1	3				4
Rana clamitans, Green frog		4				4
Hyla versicolor/chrysoscelis, Gray treefrog		1				1
Total amphibians	2836	8545	761	795	232	13,169

Rana clamitans; and eastern spadefoot toad, *Scaphiopus holbrooki*) were not represented in our summer subsets of data, but they were taken at other times of year. The gray treefrog, *Hyla versicolor/chrysoscelis*, represented by one specimen in the Bennett *et al.* study, was not taken in the 1994–1996 study, but males were heard calling from the loblolly pine forest adjacent to Lost Lake. One species collected by Bennett *et al.*, the dwarf salamander (*Eurycea quadridigitata*), was not collected by any method in our study. It is probable that the dwarf salamander was extirpated from the Lost Lake amphibian community as a result of restoration activities. This species is common to most Carolina bays on the Savannah River Site (Gibbons and Semlitsch, 1991) where it may be found in the moist leaf litter and under debris in the margins of these wetlands. The conversion from mesic forest to open herbaceous community in the area surrounding the bay apparently accounts for the loss of this species.

Comparison of summer samples among years revealed dominance by the same one to three species for all years (Table 8). In the Bennett *et al.* study the eastern narrowmouth toad was the numerically dominant species (28% of total captures), followed closely by the southern toad (22%) and the eastern newt (21%). Of 11,381 total amphibian captures, approximately 42% occurred in the hardwood forest and 29% occurred in each of the two managed pine forests. These patterns are similar to those seen in our study, although a higher percentage was captured in the hardwood habitat in 1994–1996. However, summer amphibian captures in 1994–1996 were down 88% (n = 1788) compared to 1977–1978. This was in spite of totaling three summers for our study instead of two as for Bennett *et al.* The eastern newt, although the most abundant salamander, represented a much lower percentage (2%) in the 1994–1996 samples. Numbers of eastern newts were apparently lower because there were no migrations of newly metamorphosed individuals as occurred in 1978.

Differences in Lost Lake amphibian abundance and diversity between 1994 and 1996 are comparable to natural differences reported by Pechman *et al.* (1991) for amphibians inhabiting other wetlands on the Savannah River Site. However, comparison of data for the summers of 1977–1978 reveals a significant overall reduction in amphibian species abundance (88%) and diversity for all three forest habitats following the restoration of Lost Lake. The restoration activities eliminated all leaf litter and woody debris from the wetland and its margins and converted mesic hardwood-shrub and pine-shrub communities into an open herbaceous "old field" community in the immediate vicinity of the wetland. We believe the dramatic decrease in abundance seen in the comparison of the summer samples was the result of habitat alteration during the restoration of the Carolina bay. It is also possible that these activities contributed to the high relative abundance of southern toads seen in our 3 y study. Although the southern toad is a dominant woodland amphibian species, it is quite ubiquitous and readily occupies open grassy habitats and breeds in open ponds. The dense grasses now surrounding Lost Lake provide increased cover and possibly allow greater survivorship of southern toad metamorphs.

Annual migrations of metamorphs and breeding adults of southern toads did not occur during the summer sampling periods in 1977–1978 or in 1994–1996. Therefore, there were proportionately fewer southern toads in the summer sampling periods than in the year-round study. This factor, and the fact that fewer individuals of all species were captured in the summer sampling periods, resulted in higher evenness and diversity indices for the summers. It is clear that the results of our summer sampling period and those of Bennett *et al.* (1980) do not accurately reflect the overall diversity of these forests.

In spite of the practice of controlled burning in the pine plantations, our results indicate that the managed pine forests support almost the full amphibian community at Lost Lake,

although in significantly lower numbers. However, the unmanaged mixed hardwood forest appears to be the preferred habitat based on relative abundance, surface activity and species richness. Mitchell *et al.* (1997), working in the central Appalachian mountains, found patterns of diversity, species richness and general abundance similar to the patterns reported here. They found that the combination of mature hardwoods and proximity to wetlands determine patterns of amphibian distribution and abundance. Forest managers in the southeastern region should consider the value of mixed hardwoods as refugia for amphibians when developing landscape management plans.

Our study shows that the importance of continuous longer term monitoring cannot be overstated. The results of our short term summer sampling periods contrasted dramatically with those of the longer term, 3 y continuous study. Our results suggest that conservation, restoration or forest management strategies based on results from single season monitoring alone may fail.

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SUBMITTED 20 APRIL 1998 ACCEPTED 4 AUGUST 1999

GULF STURGEON

Scientific Name

Acipenser oxyrhynchus desotoi

Common Names

Gulf sturgeon, Gulf of Mexico sturgeon, Atlantic sturgeon, common sturgeon and sea sturgeon.

Status

Listed as a Federally threatened species on September 30, 1991.

Description

Easily recognized by rows of bony plates, or scutes along body. Can grow longer than nine feet and weigh in excess of 300 pounds. The suction type mouth is located beneath the head.

Diet

Bottom dwelling organisms; amphipods, isopods, crustaceans, and marine worms.

Habitat

Gulf of Mexico. Bays and estuaries in Florida, Alabama, Mississippi and Louisiana. Major freshwater rivers from the Suwannee River, Florida to the Mississippi River.

Spawning Habitat

This anadromous species migrates from salt water into coastal rivers to spawn.

Life History

Spends most of its life in rivers. Long-lived up to 70 years. Requires 9 to 12 years to reproduce which makes it vulnerable to overharvest and habitat change.

Natural Enemies

None.

Threats to Survival

Barriers to spawning grounds (dams), habitat loss, poor water quality.

Interesting Note

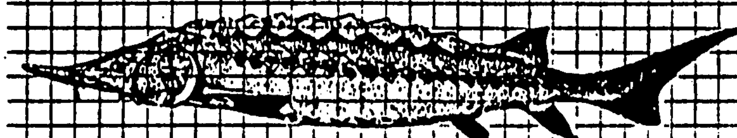
Fossil ancestry of this primitive fish dates back 200 million years. In the late 19th and early 20 centuries, sturgeon were harvested for their edible flesh and eggs for caviar.

WANTED

INFORMATION ABOUT

➡ SIGHTINGS &
➡ LOCATIONS

Historic and Recent



GULF STURGEON

Call Collect

(904) 769-0552

U.S. Fish & Wildlife Service
1612 June Avenue
Panama City, FL 32405

Restoration Plan for the Gulf Sturgeon

The Gulf sturgeon was listed as a Federally threatened species on September 30, 1991. Information is requested to help us develop a restoration plan for the Gulf sturgeon.

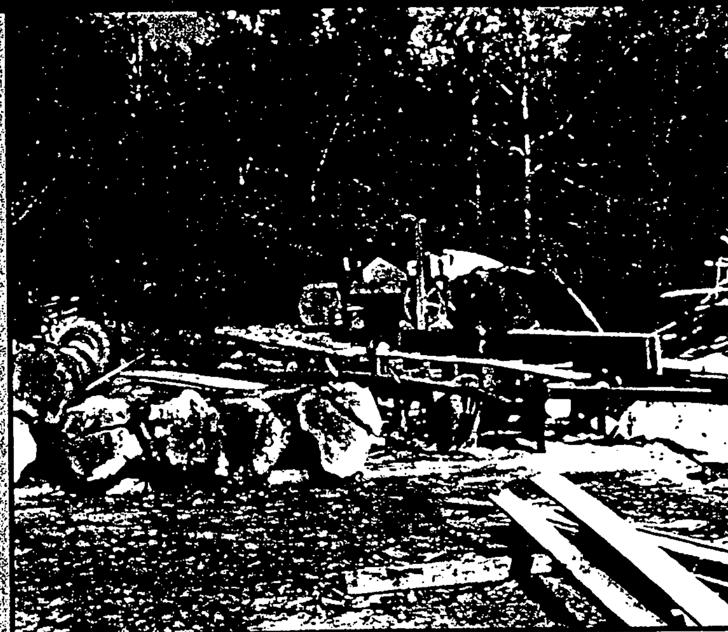
Take of this fish is prohibited by state and Federal law.

Recoveri LOST Treasur

by samual j. ard

In the mid-1880s, Adlee Bruner's great-great uncle packed his few possessions and walked from north Alabama to Point Washington in Walton County, Florida. There he went to work at a large sawmill near the Choctawhatchee River.

A century later, the 38-year-old Bruner follows in that family tradition as the owner of Riverbend Lumber Company, also located on the banks of the Choctawhatchee River. The Riverbend Lumber Company specializes in the recovery and milling of deadheads, the cypress and heart pine logs that sank to the bottom of Florida rivers in the final years of the 19th century and into the early decades of the 20th century.



PHOTOS: DWIGHT M. SUMNERS/FLORIDA STATE ARCHIVES

Milling cypress at Riverbend Lumber Company.

Timber fueled Florida's economy in the early years of statehood. The state's virgin forests were home to enormous trees that yielded high-quality woods, the likes of which can't be found today. The deadhead logs are the remnants of those forests.

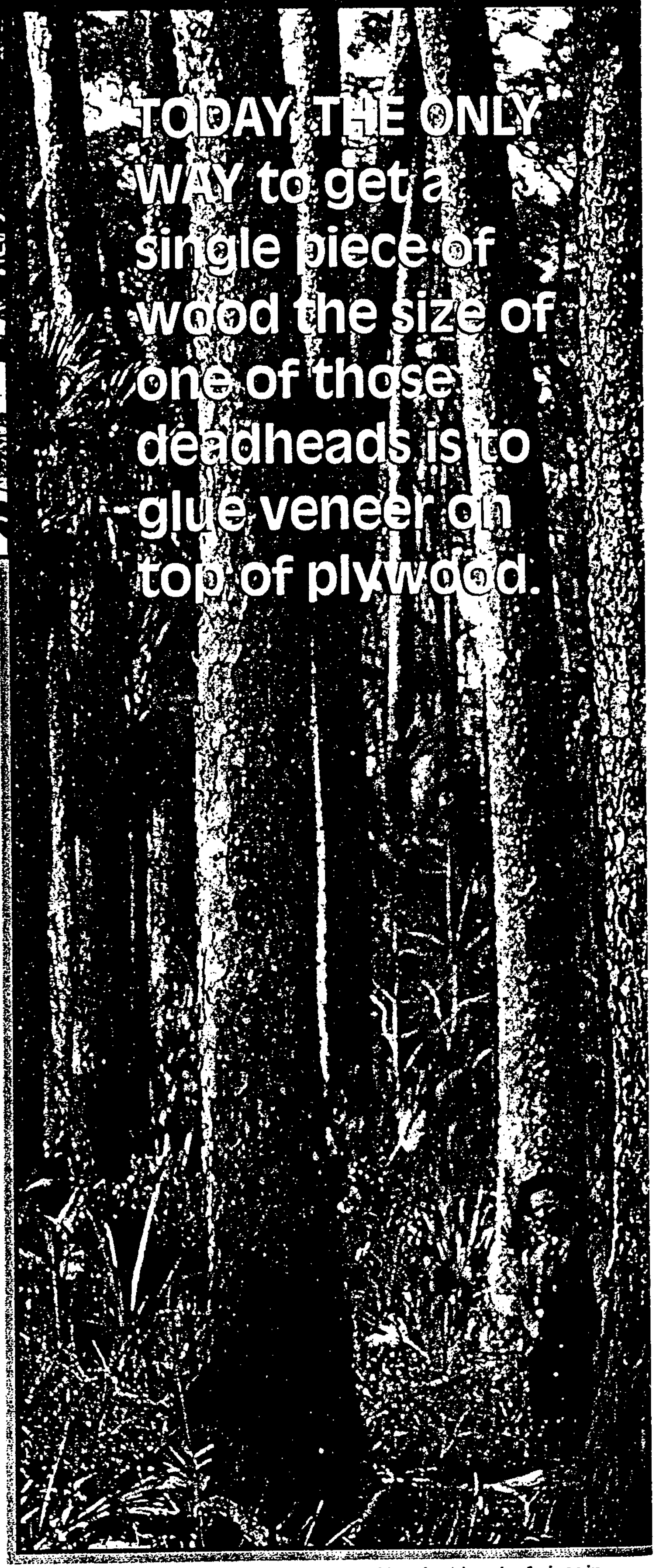
In one of his final acts as governor, Lawton Chiles presided over a Dec. 10, 1998, meeting where the Cabinet gave its approval to a process for recovering deadheads from Florida's rivers.

Bruner estimates that up to 300,000 board feet of high-grade lumber rests at the bottom of the Blackwater and Yellow rivers alone. Retailed at \$4.50 to \$8.00 per board foot, the deadheads are bringing sawmills along north Florida's rivers to life with the promise of much-needed jobs and prosperity.

BUILDING ON A SWAMP

When Florida was accepted into the Union in 1845, the federal government surveyed the entire state and classified almost 20 million of Florida's 34 million acres as "swamp and overflowed lands." The federal government transferred ownership of those 20 million acres to the state of Florida. They were lands considered unproductive until someone went to the considerable expense to drain them.

Soon, Florida's government began selling the property to a few Northern industrial magnates and the small number of settlers who chose to make Florida their home. If you own any piece of Florida property there's a good chance you can trace the chain of title back to those 19th century transactions since they involved more than half the land in the state.



A late 19th century logger stands dwarfed by giant longleaf pines in one of Florida's virgin forests.

PHOTOS: DWIGHT M. SUMNERS

Adlee Bruner in the woodyard at Riverbend Lumber Company.

A deadhead log marked with the Bruner family's brand.

Timber of this size and grade is unavailable because there are no virgin or old growth forests remaining in Florida. Most of the United States was timbered during a 50-year period beginning around 1880. One Florida company, the Putnam Lumber Company, harvested over 350,000 acres in a 20-year period. The Florida Depart-ment of Agriculture estimates that, because of reforesting, Florida is now on its fourth-generation forest. Modern corporate and private landowners typically place their timber holdings in rotations of 25 to 50 years, depending on the type of product they market from the wood. The deadheads found in the rivers are aged anywhere from 100 to as much as 2,500 years old.

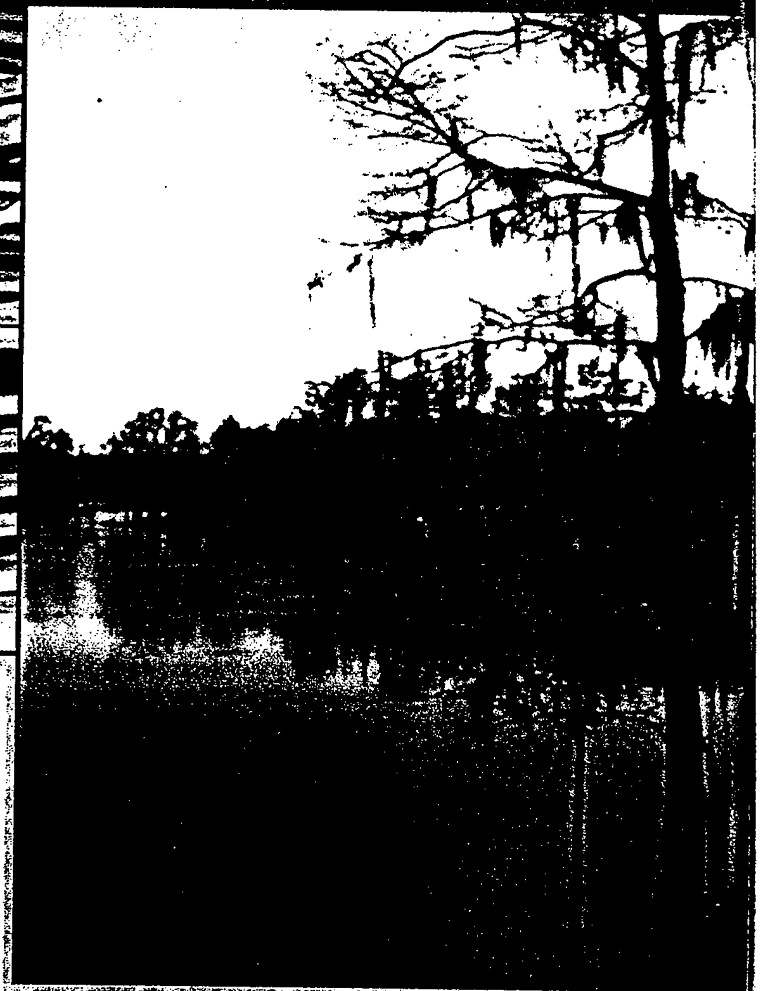
BACK IN BUSINESS

The Bruner family recovered deadheads from riverbeds for years until the practice was declared illegal in 1974 because of concerns that it would disrupt fish habitats. With a booming economy, demand for high-quality wood convinced Bruner to embark on a fight to regain permission to recover the logs.

Earlier this year, the environmental impact of recovering deadheads was studied by the Florida Game and Fresh Water Fish Commission, as well as other environmental regulators and experts. They discovered the logs contributed little, if any, environmental benefit to the rivers.

Attorney General Bob Butterworth, at the request of DEP, then investigated the issue of the legality of recovering the timber. The attorney general determined that since the river bottoms are state property, the state owns the title to unbranded logs. All branded logs are the property of the owner of the brand. Anyone recovering a branded log must report his find to a law enforcement officer, who then notifies the brand holder or advertises the find for 90 days. If no one comes forward with a valid claim, the property can be returned to the finder.

Milled cypress awaits shipment from Riverbend Lumber Company.



The Choctawhatchee River as it flows past Riverbend Lumber Company: an ancient river waits to surrender its treasures from Florida's past.

His lowest-priced product is air-dried, rough cut lumber, which sells for about $3 per board foot. The price rises if the customer wants the wood milled, planed, or dried to other specifications. For example, wood three-quarters of an inch thick, tongue and grooved for flooring or paneling, and kiln dried to less than 5 percent moisture content is worth about $4.50 per board foot.

Bruner estimates that in less than two years he will have recouped his investment and begun to make a profit. "This business is not for just anybody." Bruner warns. "Groping around on the bottom of a cold, dark river isn't for the faint of heart. But it's fun, it's creative, and my customers are thrilled to learn the history behind the construction of their home."

To increase his potential inventory, Bruner has researched the laws on timber brands. He negotiates leases with the heirs of the brand owners, and can now claim title to many of the logs he locates.

"I pay the brand owners a flat fee," says Bruner, "around $200 per thousand board feet. I've seen logs that contained as much as 1,500 board feet. It's a good way for them to make some easy money on something they gave up on as lost many years ago."

William Rosasco III is another Floridian with a vested interest in recovering the logs. His family owned one of Florida's largest sawmills in the tiny northwest Florida town of Bagdad at the turn of the century. Rosasco still owns title to over 250 brands that can be found on logs in the Blackwater, Yellow, and Shoal rivers in Santa Rosa and Okaloosa counties.

The Rosascos were among the most successful and prominent business people in the early years of statehood. The family came to Florida from Italy in 1840. They harvested and milled their Genoa Select brand heart pine from their lands, and exported most of it to Italy.

"Just knowing I've got a lot of family history on the bottoms of these rivers," says Rosasco, "I'm elated that the business my grandfather helped start over 100 years ago is actually still alive and well. I can't wait to see the first house, or library, or conference facility built with this wood."

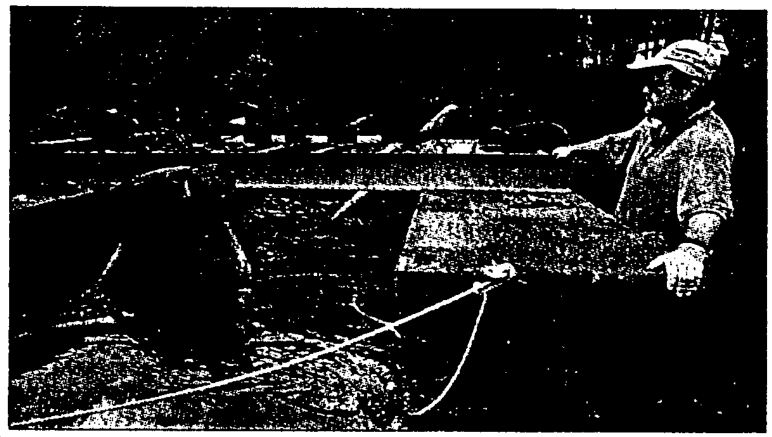
Rosasco also notes, "Since the net ban, our coastal counties have been struggling for economic development. This industry could put a lot of families back to work." ■

Samual J. Ard is an attorney and sole practitioner in Tallahassee. He worked with Adlee Bruner and William Rosasco as a consultant in the effort to gain permission to resume the salvaging of deadheads.

Northwest Florida Daily News

SUNDAY, AUGUST 8, 1999

Rivers flow with timber, profits, protests



Alton Reddick (left) and Andy Coleman use a barge equipped with a winch to pull a "heart" pine dead-head log off the bottom of the Blackwater River.

Daily News
DEVON RAVINE

■ "Dead-head" loggers are protective of their lucrative trade, earning up to $3,000 per log, but environmentalists say the practice harms rivers.

By DUWAYNE ESCOBEDO
Daily News Staff Writer

BAKER — Pushing a custom-made pontoon boat just off the banks of the Blackwater River into waist-deep water, Alton Reddick gets ready to begin his day of logging.

For almost two weeks, the 55-year-old Bruce resident has hardly strayed from where he ties up his boat. But already, 33 telephone pole-sized timbers lay stacked in shallow water near the Blackwater's edge.

He's not your typical lumberjack.

Reddick, who has lived all his life on the Choctawhatchee River in Walton County, is what's known as a "dead-head logger." He has been one ever since he turned 15.

The practice requires retrieving pre-cut timbers, or "dead heads," that sank throughout Northwest Florida riverbeds as much as 150 years ago.

Timber companies that were clear-cutting virtually the entire range of virgin longleaf pine and bald cypress stands between the 1850s and 1920s left the logs behind when they broke off rafts that were floating them down the rivers to nearby sawmills.

Reddick and Andy Coleman, who are working together and formed a company, River Bend Trading Co., are happy to pick up the premium wood, which once again is in high demand.

"This is the way I make my living right now. I don't want to go back to iron work," said Reddick, who worked for Iron Workers Union Mobile Local 798. "The state shut us down three four years ago, arresting a lot of people for this."

Environmental fears

Many environmentalists maintain dead-head logging should still be a crime.

Opponents of the practice fear removing the timber will lead to massive erosion resulting in poorer water quality, and to permanently damaged plant and wildlife habitats, which would harm mussels, gulf striped bass, endangered gulf sturgeon and other creatures.

The state stopped issuing permits and banned dead-head logging in 1974 when the Game and Freshwater Fish Commission concluded it disrupted or permanently damaged the places where fish lived.

Because the rivers run through so many rural areas, enforcement was rare and the logging continued.

After years of petitioning and observation of logging operations, however, state environmental agencies dropped their opposition.

And in January, the Florida Department of Environmental Protection began allowing recovery of the precut timber from riverbeds again.

For a $5,500 permit to work on the riverbeds owned by the state and a $500 permit to dredge, dead-head loggers can retrieve the coveted wood from approximately 20-mile stretches of rivers. After a year, the state plans to evaluate the practice and decide whether to let it continue.

So far about a dozen permits have been obtained between Pensacola and Jacksonville, with the first issued in April. Reddick and Coleman received the first permit in Okaloosa County, getting permission to pick up logs on the Blackwater River between

Please see TIMBER/A5

TIMBER

From **A1**

the Alabama and Santa Rosa County lines.

The former Game and Freshwater Fish Commission, now called the Florida Fish and Wildlife Conservation Commission, has said pre-cut lumber isn't as attractive to fish as trees blown into the water, which still have their tops and roots intact. And since sand partially covers many of the logs, they become even less appealing to fish.

But Jim Williams, a U.S. Geological Survey biologist at the Florida Caribbean Science Center in Gainesville, calls the dead-head logging permitting "absolutely negligent," and fears destruction to the rivers and water life.

"They don't have any good information right now to make any good evaluation," Williams said. "It may set off an erosion event going miles upstream. These things may have been put there artificially 150 years ago but now they have become part of the river bottom. You don't just go rip the place up."

Gordon Roberts, a leading DEP dead-head logging authority, points out that a host of restrictions, such as prohibiting lumber recovery from river banks or bends, will reduce damage from the activity. He adds the permits will help to impose more self-policing.

"There are so many rivers and so many private landings to catch someone in the act illegally is awfully hard," Roberts said. "But if you have to buy a permit and now you see someone, you're going to turn them in pretty darn quick. But I won't tell you there still won't be some illegal harvest going on."

Tiana Burton, Sierra Club Northwest Florida Group conservation chairwoman, worries there's a lack of oversight, though.

"Sure there's a lot of conditions, but I'm concerned they're not really being observed," she said. "You're giving somebody a permit for 20 miles of river and there really isn't any good monitoring."

Eric Buckelew, who's in charge of the logging permits for DEP's Northwest District, and other biologists are making spot checks and doing testing.

"We'll see what kind of damage it's causing the environment and see how things work," he said. "It's an industry that's been going on for a long time. But until we get some control over what's going on, we really don't have any concrete data one way or another."

To Reddick and Coleman, dead-head logging makes environmental sense. Reddick says the rivers ran 20 to 30-feet deep during his childhood but have filled up with sand, and removal of the lumber will open up the rivers again.

Adds Coleman: "Every log we retrieve is saving one out in the rainforest."

> "Every log we retrieve is saving one out in the rainforest."
>
> **ANDY COLEMAN**
> "dead-head" logger

AUGUST 8, 1999 Daily News

Pulling up the pine

Meanwhile, their excitement builds as a winch on the boat twists and pulls up a partially submerged 32-foot "heart" pine, which the old-growth, first generation longleaf pine is called, from its oxygen-free underwater sanctuary.

During the tug-of-war, the winch's cable frays and then snaps. But after about 30 minutes, the heart pine pops up, revealing a glossy, rose color.

"This is the finest pine in the world," said Coleman, with a wide grin. "It's gorgeous."

The lumber is a treasure, too, because it fetches from $2.50 to $10 a board foot. A board foot equals a piece 1-inch thick and 1-foot square.

A "curly" pine, one with lots of knots on the outside that give the wood grain a swirly pattern, brings even more money, retailing for as much as $51 a board foot.

One recovered heart pine, which is dried in a kiln for up to two weeks before being cut, can contain between 200 to 300 board feet. In other words, one log can bring in $500 to $3,000, depending on its size and quality.

More than 100 years ago, longleaf pine stands stretched over about 85 million acres from Virginia to Texas. Today, an estimated 5,000 acres remain, 1,000 of those in Florida.

Northern and European timber companies moved in and essentially clear-cut the prime timber during a 40-year period, making heart pine virtually extinct by 1910.

The heart pine was declared "King's wood" and considered an excellent all-purpose timber used for ship-building and home-building all over colonial American and Europe. It became the top wood of choice because its tight rings, hardness and high resin made it resistant to fire, water and insects. Plus, it is very durable and has rich colors, ranging from dark golden yellow to red.

The only way to get the 20- to 40-foot-long logs to sawmills along the coast was to drag them by oxen and steam engine to the closest rivers. There, loggers tied them together in rafts, usually as wide as the river and five to seven miles long.

During the trip, many sank. With no way to retrieve them and lumber so plentiful, they were forgotten. No one knows exactly how much timber remains underwater.

A treasure of wood

William Rosasco III, whose family owned one of Florida's largest sawmills in because he believes it will help him to better recoup some lost timber that belonged to his family's sawmill. Much of the lumber still contains his family's brands and he has leased the rights to dead-head loggers for about $300 per 1,000 board feet.

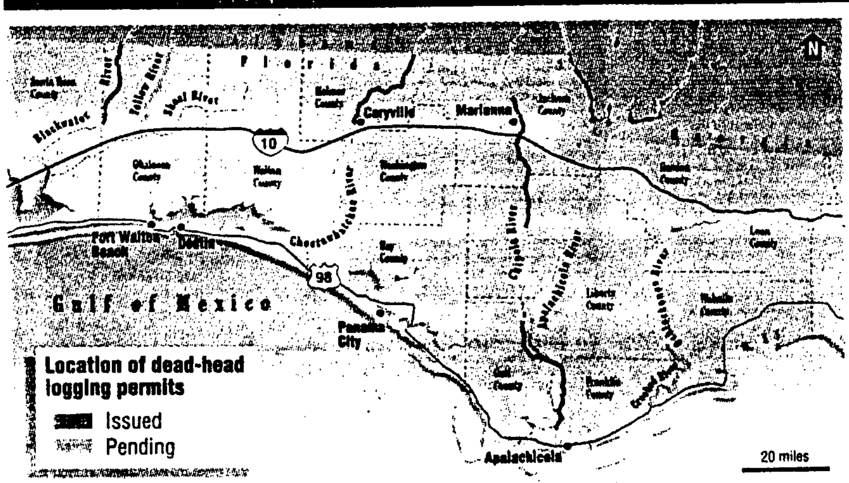
"So much of it has been stolen," said the Milton builder and developer. "It has been a considerable financial loss to us. As long as some of it has been lying down there, it's exciting to see some of our brands now coming up (legally)."

Having floated up and down the Blackwater River picking out dead heads jutting out seemingly left and right, Reddick marvels at how much timber the river still claims that is just waiting to become flooring, molding, stair parts or furniture.

"All my life cypress was in demand and no one was interested in pine," said Reddick, who sold dead-head cypress for restoration projects at George Washington's Mount Vernon estate and Thomas Jefferson's Poplar Forest octagonal house.

"You'd pick pine up and drop it. You couldn't sell it. There's quite a bit left, but not like it used to be. There's probably millions (of board feet), but we'll never see it all."

■ **Staff Writer Duwayne Escobedo can be reached at 936-8600 or**



Source: Florida Department of Environmental Protection, Northwest District

Daily News/KEN MAINES

In the photo above, a pair of dead-head pine logs recovered from the Blackwater River sit partially submerged in water, waiting to be transported to a sawmill. The old-growth wood is prized for its tight ring structure, which makes it very resistant to weather and termites.

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Uprooting fallen history

The logging of valuable longleaf pines laying in North Florida rivers outrages some anglers and environmental activists.

By CRAIG PITTMAN and JULIE HAUSERMAN

ON THE YELLOW RIVER -- Like fossils preserved in amber water, the longleaf pine logs lay beneath the rippling waves, as fresh inside as the day they were cut a century ago.

The remnants of a vast forest that no longer exists, the 30-foot timbers were among thousands that loggers once floated down the Yellow River to a sawmill. The logs snagged on obstructions and jammed into the river bottom and banks. To the loggers, the lost timbers were deadheads, too much trouble to retrieve.

Over the decades, the deadheads became part of the river. Where woodpeckers once nested, sturgeon and mussels found a home. Every angler for miles around knew that the area around the deadheads was where to find the biggest bass, bream and bluegill in Okaloosa County.

Then, about a month ago, someone pulled 50 of the ancient logs out of the Yellow River's bends. Using steel cables and floating winches, a crew yanked them out of the river and left them piled on a sandbar.

Since the state began issuing permits in February, deadhead crews have pulled 3,000 logs out of seven rivers across North Florida.

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To these crews, the deadheads are like buried treasure because developers and homeowners will pay top dollar for such rare timbers to be turned into wood floors, stairs and furniture. One log can fetch as much as $3,000.

Anglers, scientists and environmental activists are steaming about what deadhead loggers are doing to the state's waterways. They will bring their complaint to Gov. Jeb Bush and the Cabinet this week.

"It's against Mother Nature to clean out this river," fumed Larry Welch, 48, of Crestview, who grew up fishing around the deadheads in the Yellow River. "It's totally destroying the fish habitat. They're stripping the river."

Federal wildlife officials fear pulling out the deadheads harms endangered species such as the Gulf sturgeon and rare freshwater mussels such as the purple bankclimber and the Chipola slabshell. Biologists worry that the deadheaders are damaging the rivers by weakening the banks and ruining water quality.

But the deadhead loggers contend they are helping the environment, not hurting it.

"These logs are already cut," pointed out Frankie Smith of Westville, who in seven months pulled some 200 deadheads out of the Choctawhatchee River. "We're not going out there cutting new wood . . . We wouldn't hurt nothing anywhere."

Tallahassee attorney Sam Ard, who represents a company called River Bend Lumber that harvests deadheads from the Yellow River, contended the longleaf logs are as artificial as a block of concrete dumped in a stream.

"They need to come out if you want to create a natural system," he said.

The state Department of Environmental Protection wants to keep deadhead logging legal, yet even the DEP's own scientists agree that pulling the old logs out hurts the rivers' wildlife. So DEP officials have suggested a compromise: Order the deadheaders to cut fresh trees and sink them into the rivers to replace what the crews yank out.

To Welch, that seems spectacularly stupid.

"What are they going to do?" he asked. "Bring in pile drivers so they can drive them into the riverbeds so they'll stay -- and cause even more damage?"

'The finest timber'

Traditional timber harvesting still goes on near the Yellow River. Trucks loaded with spindly logs whip along the Hog and Hominy Road. The tang of sticky pine tar lingers in their wake.

But those slash pines are a poor cousin of the magnificent longleaf that once ruled Southern forests. Hailed as "the finest timber tree the world has ever known," the longleaf is valued for its honeyed patina, tight grain and natural resistance to insects.

Ard's client is selling deadhead lumber from the Yellow River to homebuilders at Rosemary Beach, a Walton County development that mimics the look of a small town from a bygone era. The Gulf-front houses, with their elegant pine floors, go for $1-million.

A century ago, what made the longleaf valuable was its strength and apparently inexhaustible supply. In the impoverished post-Civil War South, timber crews clear-cut millions of acres, floating the logs downriver lashed together into rafts that stretched for miles. Sawmills ran night and day producing shingles, barrel staves, ships, forts and houses.

By 1930, the Southern longleaf forests were all but gone and biologists were calling their destruction "one of the major social crimes of American history." Evidence of the crime lingered in the rivers: the deadheads, which would have rotted in the open air, were sealed away safe in their watery vault.

Since then, any poor Florida farmer who needed lumber for his barn might wade into a river and pull out a deadhead, but most logs stayed where they sank. One estimate says 300,000 board-feet of high-grade timber remains beneath the Blackwater and Yellow rivers alone.

In 1974, Florida officials concerned about the potential harm to fishing outlawed removal of the deadheads. In the 1990s, though, the market for deadhead lumber from Southern rivers has boomed. Deadhead timber adorns everything from the mansion of computer billionaire Bill Gates to the corporate offices of the television show This Old House.

The rising demand drove a push to overturn Florida's ban. A year ago, DEP officials persuaded Gov. Lawton Chiles and the Cabinet to make deadheading legal. DEP officials said harvesting the deadheads would "improve the fisheries and recreational use of previously inaccessible water bodies."

Not until after the program was approved was a DEP scientist dispatched to survey the impact on the Yellow and five other rivers. He concluded that pulling out the

deadheads would harm the wildlife.

Nature's property

This summer, former state forester Vernon Compton was kayaking through Blackwater River State Forest when he noticed something troubling: Deadheads had been yanked from the river's banks and live trees had been cut, apparently to clear a path to pull out the deadheads.

The state's deadhead logging permits say that no live trees are to be cut and no logs are to be pulled out of the banks, which would damage the structure of the river. So Compton dutifully notified the DEP -- along with the Florida Wildlife Federation and the U.S. Fish and Wildlife Service.

Federal wildlife experts, who had not been consulted before last year's Cabinet vote, began questioning DEP officials about the impact on endangered species.

Meanwhile, FWF President Manley Fuller fired off a letter to DEP Secretary David Struhs urging him to revoke the deadheader's permit for damaging a state forest.

Struhs wrote back that the deadheader had been warned.

Compton's discovery highlighted the biggest weakness in the deadhead program. Although DEP officials have boasted to the Cabinet they are doing an outstanding job policing the deadheaders, the agency actually has done little to pursue complaints.

Special Agent Chuck Webb of the Panama City DEP office says his agency is stretched too thin to keep a close watch on so many deadheaders. He is the only DEP investigator for much of the Panhandle. Only a week ago was he at last equipped with a boat.

This month Welch, the Crestview angler, took Webb out on the Yellow River to see the pile of 50 logs, some of them pulled out of the river banks in violation of the state's permit. Webb said he could not charge anyone, not even the only deadheader with a permit to work that area.

"The problem is there are no eyewitnesses," Webb said. "We've got to catch them at it."

Frustrated, Welch organized a boycott among the owners of the Yellow River's private boat landings. They have all refused to let the deadheaders cross their property, so the deadheaders cannot retrieve their harvested logs unless they can float them down to a public landing miles away.

"There ain't no way they can float a log down that river!" Welch crowed. "A lot of places it ain't even a foot deep."

Last week Welch and landing owner Harold "Sky" King, 65, drove to Tallahassee to lobby Cabinet aides to outlaw deadheading. Deadheaders in jeans and camouflage jackets also crowded into the meeting room normally filled with dark-suited power brokers.

Russell Bourkard, who has been harvesting deadheads since the 1950s, told Cabinet aides there are still plenty of fallen trees providing a haven for fish.

"I wish somebody would see how much habitat is really there," he said. "What we pull out is only a small portion."

But the gray-haired King, who is building a cabin of fragrant cedar on the Yellow River, said he believes the deadheads now belong to nature, not man.

"Hell, they've been there for a hundred years," he said. "They're part of the ecosystem now."

-- Times researcher John Martin contributed to this report.

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LOCAL

State places 4-month moratorium on pulling logs from riverbeds

By Anton Caputo
News Journal staff writer

The state has placed a four-month moratorium on new permits to pull old-growth lumber from Florida riverbeds almost a year after legalizing the controversial practice.

During that time, it will look into a bevy of environmental complaints associated with the 23 use agreements it has issued since approving the logging in December 1998.

The Blackwater River and the Yellow River are among eight in North Florida that have been affected in the past year.

More than 3,000 logs have been harvested from beneath the rivers' waters during that time.

The practice is commonly known as deadhead logging and the prize is the remnants of the virgin longleaf pine forests that were cut decades ago and floated down the rivers to lumber mills.

With the disappearance of the trees, what's left at the bottom of the rivers has become a valuable commodity. A single log can sell for as much as $3,000.

"It's the old story of supply and demand," said Bagdad resident Charles D'Asaro, who is worried about damage the logging might be causing to the Blackwater River.

Proponents of the practice argue that the logs were introduced to the river by humans and aren't part of the natural habitat.

But many have been sitting at the bottom of rivers for 100 years or more, and they have become an integral part of the ecosystem, said Manley Fuller, president of the Florida Wildlife Federation.

The practice had been outlawed in Florida since 1974 before the Cabinet decided to legalize it last year. Loggers aren't supposed to harvest logs embedded in a river's banks or pull out trees that have fallen into the river.

But opponents of the logging practice say these rules are often ignored and not strictly enforced.

"One of the problems is that there is no one to enforce the conditions," Fuller said. "I don't think wildlife officers are checking on these things with any regularity. I'm not knocking them. They are few and far between and have other jobs."

Some federal wildlife officials have said they are worried about the logging's impact on endangered river species.

During the next four months a working group of state and federal agencies will investigate the practice and report back to the Cabinet at its April 25 meeting.

PENSACOLA News Journal
MONDAY, DECEMBER 20, 1999

EDITORIALS

DEP should halt river 'deadheading'

The state Department of Environmental Protection didn't go far enough in its moratorium on pulling old-growth lumber — deadheading — from North Florida rivers.

DEP has put a four-month moratorium on new permits pending Cabinet review, but ought to halt all deadheading. The Cabinet, rather than waiting four months to study the matter and reviewing it in April, should permanently suspend the practice.

By waiting until April, DEP and the Cabinet are assuring that more damage will be done to North Florida Rivers, including the Blackwater, Yellow and Chipola in Northwest Florida.

The practice had been illegal since 1974 until, for reasons many people still don't understand, it was suddenly resurrected in 1998 by the Cabinet at the behest of DEP.

The problem with deadheading is that it disturbs the river bottom, dislodging sediment and opening it up to more erosion, and destroys fish habitat that has been in place for many years.

ENVIRONMENT

By waiting until April, DEP and the Cabinet are assuring that more damage will be done to North Florida rivers.

Erosion and sedimentation are a prime river problem in the Blackwater River State Forest, and deadheading only aggravates the problem.

Proponents — whose real interest is selling the logs — argue that they're merely cleaning snags out of the river. They say that the logs, remnants of Northwest Florida's turn of the century lumber boom, shouldn't be in the river because they were introduced by man's logging operations.

It's correct that the logs are the result of logging. But most of them have been in the river for 100 years or more, and in that time nature has done what it has always done and made them part of the river ecosystem. And of course naturally occurring snags have always been part of the river ecosystem.

Through the long years, the snags have slowed the rivers and created deep pools of slow-moving water that help fish and other wildlife thrive. Pulling the logs out is destroying those habitats.

Reports from fishermen and others on the rivers indicate that deadheaders are going beyond their permits and illegally retrieving logs that are stuck in the bottom or imbedded in the bank.

As usual, the state has granted permits without providing adequate manpower to enforce them. The result is damage to the rivers — and the blame rests squarely with DEP.

If this is an example of the new, tougher DEP at work, it's not good news for fishermen, canoeist and others who value healthy Florida rivers.

VIEWPOINT

DEP allows a few to pillage Blackwater and other rivers

CHARLES N. D'ASARO

The Department of Environment Protection Director David Struhs has had more than a year to show Floridians that the agency intends to enforce environmental laws.

From my perspective, which involves monitoring the Blackwater River, it appears that the agency director is quite happy helping those bent on taking environmental resources that belong to all Floridians.

Deadhead logging in Outstanding Florida Waters (OFWs) is an example. Deadheads are close-grained, resinous logs cut from old-growth forests.

When the loggers of past centuries tried to float them down rivers to the sawmills, the densest logs lost buoyancy and sank. Although some so-called deadheads were branded so that their owners could claim them, when lumber was plentiful recovery was not cost-effective and thousands were abandoned throughout Northwest Florida.

Since old growth forests have been eliminated, those ancient logs, which now belong to the people of Florida, are each worth thousands of dollars. Consequently, greed enters the picture. Some people have been stealing deadheads with impunity for years. In the late '90s, a few thieves were arrested and there were howls of protest.

In 1998, for some inexplicable reason DEP was prodded into giving deadhead loggers permits to liquidate this state property without even paying for it. And to make matters 100-times worse, DEP allowed nearly all of this deadhead logging to take place in OFWs including the Blackwater River.

OFWs are supposed to be protected from destruction sanctioned by government unless it can clearly be shown the activity is in the public interest. DEP's rules state, "It shall be the Department policy to afford the highest protection to OFWs ... No degradation of water quality ... is to be permitted."

If you look closely at the permits granted to fewer than 12 people to remove deadhead logs from OFWs in Northwest Florida, you will see that OFW status is not a factor. There have been no hearings to determine whether this liquidation of state property is in the public interest.

Those giant logs may have arrived in the rivers due to human activity, but they mimic natural tree-fall accumulating in rivers since the beginning of time. In the 1800s, log jams in streams were removed to facilitate rafting of timber. Fortunately, deadheads were the replacement. Since cellulose in wood is composed of molecules of sugar strongly bound end to end, deadheads are giant, slow-dissolving lollipops providing nutrition for the food web.

Bacteria, fungi and certain insects slowly consume the logs, and themselves provide food for fish. The close-grained wood insures that release of nutrients will be slow, especially where the logs are partially buried, avoiding the polluting effects of abundant nutrients so commonly encountered today.

Not only do deadheads provide nutrients, but they slow the flow of water, creating habitat for larger animals, especially fish. And when deadheads are removed, sediment is suspended, which smothers habitat downstream. And to make the situation worse, no one knows how many deadheads exist in OFWs, so there is no way to predict the real potential for damage.

To help 12 people liquidate the property of all Floridians, DEP assumed they would follow the rules outlined in their permits. Some of those rules prohibit removing buried logs or those in log jams or river banks, and disturbing archaeological sites.

According to reports submitted to the Florida Cabinet by citizens and environmental groups such as the Florida Wildlife Federation and the Audubon Society, there have been major abuses of the rules everywhere.

In December 1999, the Cabinet responded to complaints about the permit holders failure to follow the rules and declared a four-month moratorium on new permits. In effect that gave the present permit holders exclusive rights to continue to rip deadheads out of the OFWs without additional competition that might reduce their profit.

In fact, one holder of a permit went before the Cabinet in January and complained that the area defined in his permit had been stripped of logs, and because of the moratorium on granting new permits, he was losing money. Then Struhs said to the Cabinet, "I've actually been advised that there are probably half a dozen individuals in Florida who are in the same position ... And we believe we can probably work out an arrangement where we can actually provide them with the necessary permits ... "

This farcical situation is an example of how DEP provides the highest protection to an OFW and enforces the environmental laws of Florida. We have a beneficent DEP director offering to work with a poor fellow so he can pay his Christmas bills. What about the property rights of the people of this state?

I believe it is time for the Florida Cabinet to end this travesty and prevent removal of deadhead logs from OFWs unless it can be shown to be in the public interest. And it is also time for the DEP director to stop offering to provide favors behind closed doors and attend to enforcing the environmental laws of Florida in ways that serve all Floridians.

Charles N. D'Asaro is a resident of Bagdad.

David vs. Goliath

Small salamander, that may or may not live here, impacts Santa Rosa growth

Dawn Dodge

A virtually unknown amphibian that primarily inhabits the Southeast has gained notoriety lately, challenging area builders and developers. The flatwoods salamander, by virtue of its inclusion on the endangered species list since May 1999, has rerouted and even halted building projects at wetlands sites in Santa Rosa County.

Despite the fact the small, elusive creature has never been seen by scientists or developers on the disputed lands, the mere possibility that it is there is enough to warrant federal surveys to uphold the 1993 Endangered Species Act.

Among the first to feel the effect of the tiny creature was the Santa Rosa County School District. Woodlawn Beach Middle School in Navarre, set for completion in August 2000, had to redirect a roadway and parking lot to avoid the salamander's presumed wetlands habitat.

Steve Ratliff, school construction administrator, ran into the hold-up because of less than one acre of the site. The slender salamander has never been seen there, but Ratliff said that "even the possibility of an endangered species on a site constitutes a mandatory two-year study of soil and water impact."

Therefore, the Fish and Game Commission undertook plans to survey the wetlands that harbors the endangered chocolate black and gray salamander.

To avoid the time-costly survey and go ahead with the much needed school, officials adjusted the direction of a roadway that would cross the wetlands and reoriented an east-west facing parking lot to north-south to avoid building on the disputed wetlands.

Bill Pullum, a residential developer in Santa Rosa with a planned 533 acres subdivision near Navarre High School, also has been delayed because of the may-be-there, may-not-be-there critter.

Pullum, whose acreage sits where the nocturnal amphibian may reside, was forced to halt construction plans to follow federal survey regulations for dealing with a protected species.

Pullum or his family has held the land off Highway 87 for more than 30 years. When he decided to cultivate the land, both woodland and wetland, he was blocked by wildlife agencies that requested him to perform an impact survey in the eventuality of the salamander.

That hasn't been easy.

"It has been difficult to find a federally qualified person to conduct the habitat survey," said Pullum. "By the time we found someone suitable, the breeding season was halfway done."

Forget labor disputes, permit delays and the cost of cement. Move over hurricanes, another obstacle to development has timidly arrived in Santa Rosa County.

Now the survey must wait until next winter, which translates into the virtual shutdown of construction, and leaves Pullum with taxable dormant land.

The five-inch salamander creates problems for builders because its breeding ground and migratory area can range from wetland to terrestrial. Federal regulators require a 1,476-foot buffer around breeding ponds to allow for the migration of the species.

It is this requirement, among others, that causes developers problems

The flatwoods salamander is the first protected amphibian to cause development delays in the area. So how builders deal with the creature could create a template for future management of subsequent endangered amphibians around temporary breeding ponds, said Foster Dickard, a Champion International wildlife biologist.

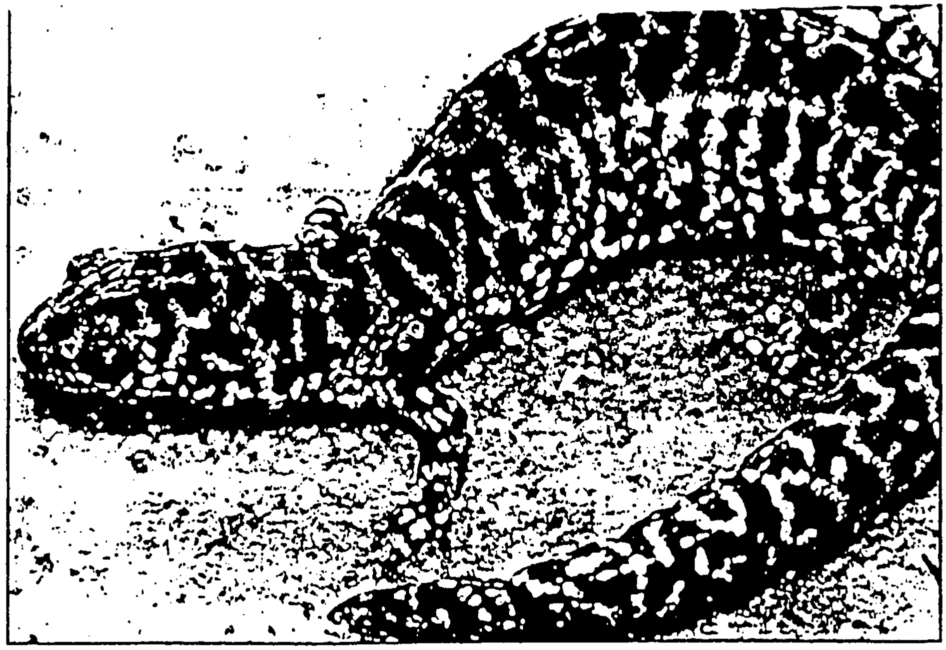
More than 80 percent of the salamander's original habitat has been destroyed through urban and agricultural development and timber cultivation. Since its last sighting in 1981, the flatwoods salamander has virtually disappeared from Alabama.

With the reduced numbers, genetics now play a large part in their plausible extinction. Hildreth Cooper, a wildlife biologist for the U.S. Fish and Wildlife Service in Panama City, said, "Some small isolated populations may not be genetically viable as the gene-pool is not large enough to sustain the flatwoods salamander."

Cooper says flatwoods salamanders are secretive in their adult life, and the only way to locate a population is to find the larvae during late winter in the wetlands.

He suggests that construction does not necessarily have to be aborted when an endangered species is located on private property. And that the government tries to help the builders determine how to minimize the impact on the animal's environment.

Under existing regulations, builders in south Santa Rosa who own wetlands must be granted a permit by the Army Corps of Engineers and then evaluated by wildlife agencies. The government then could



Courtesy Hildreth Cooper, US Fish and Wildlife Service

The flatwoods salamander may or may not be in residence in south Santa Rosa.

mandate a survey of the habitat, which could block a project for up to two breeding seasons to determine the impact of construction on the endangered animal.

Pensacola Junior College is another that may feel the presumed presence of the salamander. The college planned to build a 105-acre campus near Woodlawn Beach on U.S. 98, but construction will not begin for another three to five years said Dr. G. Thomas Delano, vice president of planning and administration.

'Ghost lizards' slowing construction

By: CARMEN PAIGE
Press Gazette Assistant Editor

Some "ghost lizards" are costing the school board big bucks.

"It's about a quarter to a third of a million dollars," Steve Ratliff, assistant superintendent of administrative services, told board members at the March 9 meeting.

At issue is the roadway for the new Woodlawn Beach Middle School in the Navarre area. The facility's construction is on schedule, however, the road is being stalled by "non-existent" salamanders, according to Steve Ratliff, assistant superintendent of administrative services.

The United States Department of Fish and Wildlife filed an appeal regarding the district's application for a federal permit surrounding the new school. The district sought a permit to fill in less than one acre, and in return, was going to purchase 40 acres of wetlands at Holley-by-the-Sea to give to the U.S. Corps of Engineers, according to Ratliff. However, officials had concern that the area could possibly be a habitat for the flatwood salamander, which was placed on threatened species list last year.

"We thought the deal was worked out," he explained.

It is now the district's responsibility to prove there are no salamanders in the area. He said he has been told the closest pod is near the Holley field and Eglin Air Force Base, however the reptiles are in "small numbers."

The district has withdrawn all federal permits and redesigned the parking lots and roadways to avoid all wetlands. He added that the district has contingency plans so if all fails, there will be a way to operate the new school and provide a proper education for students.

"This has taken a lot of engineering and time," he offered. "But, the school district is trying to comply with every rule and regulation, and to apply for the proper permits. We are working through the maze."

The audience followed Superintendent John Rogers in giving a standing ovation to the district's "Dreamers and Doers" - Monica Clonts, a junior at Navarre High, Emily Ann Sutler, a seventh grader at Jay High, and Elizabeth Drewry, a second grader at Munson Elementary. They were chosen based on curiosity, confidence, courage, constancy and creativity. Clonts is an interpreter for her parents who are deaf. Sutler is legally blind and plays in the band. Drewry lost her mother to cancer last year. Their names have been submitted to Walt Disney World for the state competition.

School board members agreed to give $15,000 to the Mary Street Park Project to provide another staff person. Mary Street officials have requested the same amount from the county and the city of Milton.

School board members will also help the Gulf Breeze Drama Department attend a three-day state competition in Orlando by funding a request for $4,168.19. Principal Cherry Fitch said the "Music Man" involves 53 students, a costumer and elaborate sets. She said this is the first time Gulf Breeze High has been invited, and is one of five schools to get an invitation.

> "We've had a lot of suspensions and a lot of alternative placements, but that goes with having safe schools."
> Rogers

Finally, three students were expelled for one calendar year with services offered at the Rader School — a Gulf Breeze Middle student for possession of prescription medication for which she had no prescription; a Milton High student for possession of marijuana in a car on campus; and, a Milton High student for possession, use and distribution of marijuana on a school bus.

"We've had a lot of suspensions and a lot of alternative placements, but that goes with having safe schools," said Superintendent Rogers. "We have high expectations for academics, and we have high expectations for good behavior as well."

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PENSACOLA
News Journal

ENVIRONMENT

Close dirt roads that cloud river, state says

Storm runoff into Blackwater threatens other waterways, too

By Scott Streater
News Journal staff writer

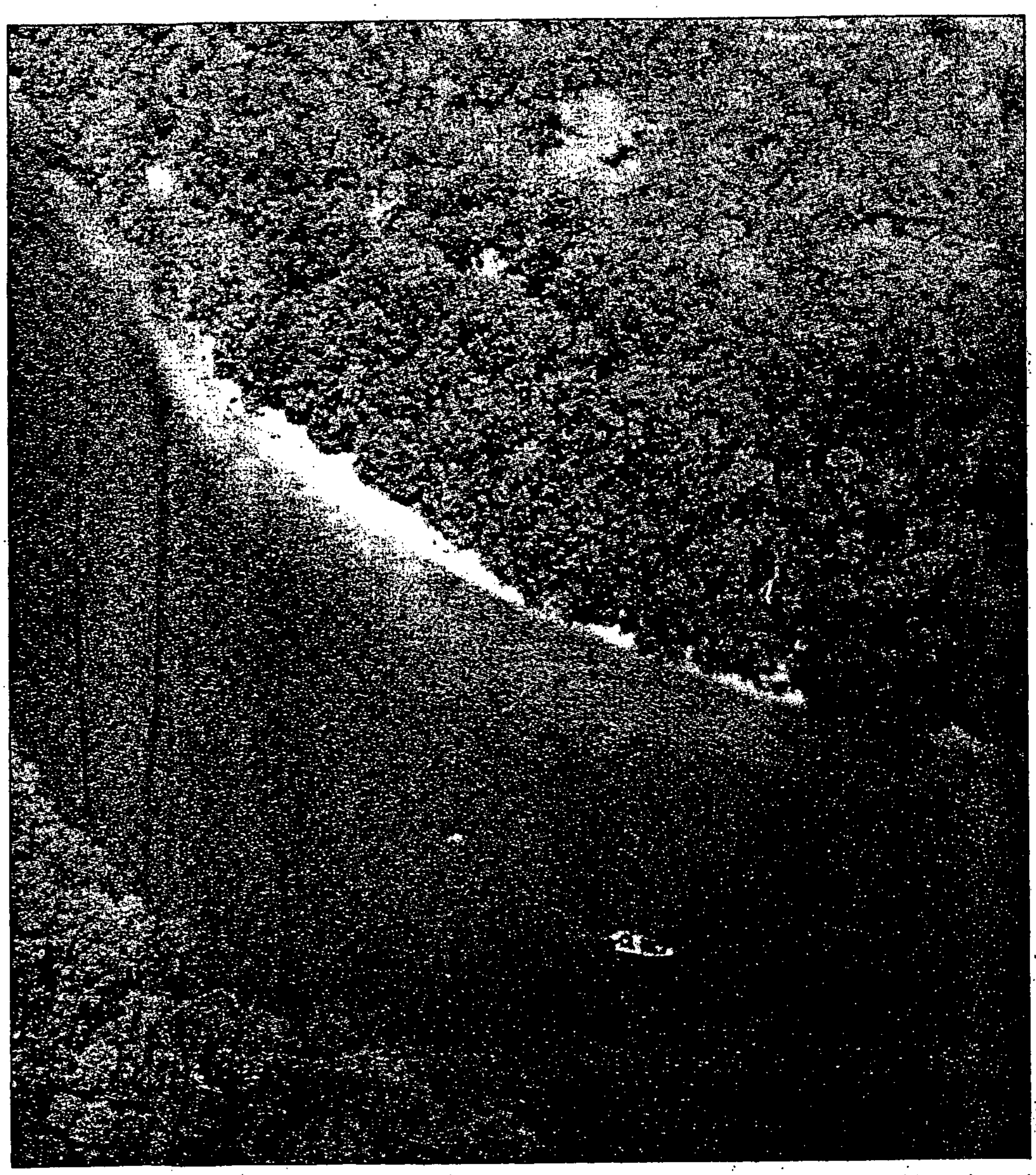
The state wants to close hundreds of miles of dirt roads in the Blackwater River State Forest because rain is washing tons of dirt and clay into nearby waterways, clouding the water as far away as Pensacola Bay.

At least 750,000 tons of dirt each year enter the Blackwater River and the various creeks and streams that snake through the 183,000-acre forest, estimates Clarence Morgan, senior forester at the forest. Spread over a football field, all that dirt would tower 26 stories high — taller than any building in the Pensacola area.

"It's like putting a freight train of dirt into Pensacola Bay every year," Morgan said, noting that the state had determined the Blackwater River receives the most sediment erosion of any body of water in Florida.

The fine dirt washes off the roads during heavy rains and runs into area waters. It then floats for miles downstream, where it blocks sunlight from reaching the underwater grass beds that nurture and protect virtually every recreational and

See DIRT, 4A



Tony Giberson/News Journal

When it rains, sediment from the miles and miles of dirt roads that surround the Blackwater River washes into the river, threatening the water's clarity and the lives of its inhabitants.

Dirt from roads clog Blackwater's water

FROM 1A

commercial marine species in the area.

Among the many environmental problems it creates, the runoff:

■ Makes some waters in the Blackwater River State Forest more shallow. The forestry service has measured sediment buildup as deep as 4 feet in some areas of the Blackwater River.

■ Raises the possibility of fish kills, because shallow water heats up more rapidly during summer months and the warmer water doesn't hold as much oxygen.

■ Covers exposed tree roots along the banks of many rivers, creeks and streams, destroying an often overlooked — and environmentally significant — habitat for fish and other marine life, said Florida Department of Environmental Protection biologist Don Ray.

The forestry service has long been concerned about erosion runoff, and it has taken steps in the past to address the problem by paving what roads it can and building along some dirt roads small ditches that catch the runoff before it reaches the water.

Last year, the division of forestry received a $25,000 grant through the DEP and used the money to close more than about 12.5 miles of roads between November and April that were planted over with vegetation. The division of forestry contributed $30,000 to the project.

The agency applied in June for a $126,000 grant to close 17 more dirt roads in the forest. Morgan said the division probably won't know whether it will be awarded

"I don't think the seriousness of the problem has been recognized by everyone (in the community) who needs to recognize it."

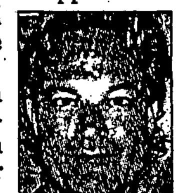
— Vernon Compton, former resource administrator at the Blackwater River State Forest

the grant until January, and the next round of road closures likely won't take place until next summer.

Even with the grants, the money will help close only a fraction of the more than 500 miles of dirt roads that officials believe are unnecessary. Morgan said about 168 miles of roads are considered primary roads, meaning they provide access for the public to natural resources and to the pockets of private land inside the forest's boundaries.

Stormwater runoff is increasingly being scrutinized by the public, elected leaders and environmental regulators as a major source of water pollution in Escambia and Santa Rosa counties.

Taylor Kirschenfeld, a DEP marine biologist, estimates that a large percentage of the cloudy water that plagues the Pensacola Bay system "is caused by runoff from dirt roads in north Escambia County and the Blackwater River area," and is directly responsible for the widespread disappearance of submerged grass beds in the last two decades.



Kirschenfeld

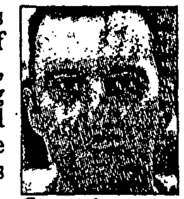
"Roads have a tremendous impact," said Vernon Compton, former resource administrator at the Blackwater River State Forest who lobbied to address the runoff problem in the forest.

"It's a real issue at Blackwater," Compton said. "I don't think the seriousness of the problem has been recognized by everyone (in the community) who needs to recognize it."

Most of the nearly 700 miles of dirt roads that weave through the Blackwater River State Forest weren't built by the state.

In many cases, the roads are little more than paths that four-wheel-drive vehicles have worn into the ground. State officials jokingly refer to these roads as being "user-engineered."

Some of the dirt runoff from these roads settles at the bottom of rivers and creeks, completely filling in one unnamed stream inside the state forest's boundaries.



Compton

That concerns Buddy Polk, owner of Blackwater Canoe Rental & Sales in East Milton, who depends on a clean, free-flowing river for his livelihood.

"Who wants to go canoe up a muddy stream?" Polk asked.

Polk said he doesn't favor the forestry service conducting widespread road closures; he just wants to close off what he calls the rarely used "pig trail roads" in an effort to preserve the pristine Blackwater River for everyone.

"I've been on them for years about this sediment runoff," Polk said of the forestry service. "The sediment and clay used on these roads really hurts a sandy river like Blackwater."

EFFORTS TO FIGHT RUNOFF

An Escambia County grand jury listed stormwater runoff as "a principal source of water pollution" that carries water-clouding sediments into area streams, rivers and bays.

In response to the grand jury report, the Santa Rosa County Commission last Thursday discussed a list of staff recommendations that includes giving added priority to paving projects that could address erosion and sediment runoff problems. Commissioners directed county staff to move forward on the list items they can address now.

Also, the Escambia County Commission has approved unanimously a resolution supporting creation of a 16-member task force of government leaders, residents, builders and environmental regulators to develop a countywide plan to control stormwater runoff pollution. The County Commission is willing to commit $20,000, which could be matched by Pensacola and the Escambia County Utilities Authority, to pay for research.

It's not the first time Escambia County has dealt with dirt-road runoff.

With the assistance of a $105,000 federal grant the state obtained, the county is testing experimental, cost-effective, dirt-road paving techniques. The goal: Pave as many of the 240 miles of dirt roads countywide with the cheap alternative methods.

Tiny Animals Form

By Jill Small Austin

"Sometimes it's the little things that drive ecosystems," said Jeff Hardesty, The Nature Conservancy's director of ecological management and restoration. "Springtails are really funny looking little bugs that only an entomologist could love. And yet they are the most numerous animal at Eglin Air Force Base. No one sees them. They will never be listed as endangered. But these unheralded animals are fundamentally important. The longleaf pine ecosystem would be impaired without them."

Beautiful animals such as the Florida black bear and Florida panther get a lot of attention for the role they play in nature. Yet Hardesty and others studying the longleaf pine forest at Eglin in the western Panhandle agree the tiny, often colorful, creature with the spring-loaded tail performs a function critical to the ecosystem.

"Springtails are absolutely essential – They break down cellulose and particles that other organisms cannot digest, creating finer compounds and nutrients that plants and animals need to survive," said Louis Provencher, Conservancy research ecologist at the Longleaf Pine Restoration Project at Eglin.

For example, cellulose, lignin, tannins and resins in plants make the plants resistant to decay, but they also resist digestion. The springtails are one of the few animals that can process these compounds.

Strength In Numbers

Ten springtail species have been recorded at Eglin, from about waist-high in the foliage down to the top of the leaf litter. While springtails can range in size from a quarter of a millimeter up to six millimeters, the most common springtails at Eglin average between one and two millimeters long, barely visible to the naked eye. Their populations can occur in the millions per hectare (2.47 acres).

"You won't see them at first; they appear to be little dots. But if you start to look, you'll see them everywhere," said Dr. Richard Snider, Michigan State University professor of zoology and entomology who has studied springtails for more than 30 years. "They look like little spiders as they hustle around on their tiptoes, walking up the sides and tops of plants."

Snider explains the work the springtail does by talking about graham crackers and peanut butter. Let's say you don't like graham crackers or can't digest them, but you eat them anyway to get the peanut butter. To eat what it wants – fungi and bacteria – the springtail has to eat the leaf litter that the fungi and bacteria grow on. But the springtail doesn't want the leaf litter and processes it out. The excreted leaf litter is

different fungi and bac...ria. along and wants to eat that the same time, excreted nu the soil – compounds of c phosphate and nitrogen, all in the functioning of the ec

A springtail characterist guishes these invertebrates, pods, from other tiny creat wild is the huge leap they t startled, a jump of about 2 their body length. Springta off a long tail wound up ur abdominal segment and he by a catch mechanism whe use. They are alerted by fle nae that sense temperature, moisture and scents.

One rare blue-and-yello found at Eglin, *Sminthuru* one of the most curious sp America because of the sha its back. Scientists do not *Sminthurus floridanus* had in Florida for more than 1C Conservancy researchers re restoration study at Eglin. ' restricted to fire-maintained in Panhandle Florida.

Burned Areas A

A surprise at Eglin, said high number of springtails maintained forests. In the p wrongly been thought of as Researchers find that spring

The adult springtail species *Sminthurus* s commonly found on Eglin Air Force Base, exhibits a complex pattern of color tiles tha form a mosaic along its body. They are only about one to two millimeters long, or about t size of the period at the end of this sentence

Key Link in

now chemically changed; it is finer and attractive to different fungi and bacteria. Another animal comes along and wants to eat that fungi and bacteria. At the same time, excreted nutrients are released into the soil – compounds of carbon, sulfur, calcium phosphate and nitrogen, all important elements in the functioning of the ecosystem.

A springtail characteristic that distinguishes these invertebrates, or arthropods, from other tiny creatures in the wild is the huge leap they take when startled, a jump of about 20 times their body length. Springtails propel off a long tail wound up under an abdominal segment and held in place by a catch mechanism when not in use. They are alerted by flexible antennae that sense temperature, vibration, moisture and scents.

One rare blue-and-yellow springtail found at Eglin, *Sminthurus floridanus*, is one of the most curious species in North America because of the sharp projection on its back. Scientists do not know its function. *Sminthurus floridanus* had not been documented in Florida for more than 100 years, until Conservancy researchers rediscovered it during the restoration study at Eglin. This rare species seems restricted to fire-maintained longleaf pine habitats in Panhandle Florida.

Sminthurus floridanus, a rare springtail, was rediscovered in Florida in fire-maintained longleaf pine forests at Eglin Air Force Base. The sharp protuberance jutting from its body is an unusual characteristic of this species.

Burned Areas Are Attractive

A surprise at Eglin, said Provencher, was the high number of springtails on plants in the fire-maintained forests. In the past, burned areas had wrongly been thought of as less zoologically rich. Researchers find that springtails respond positively

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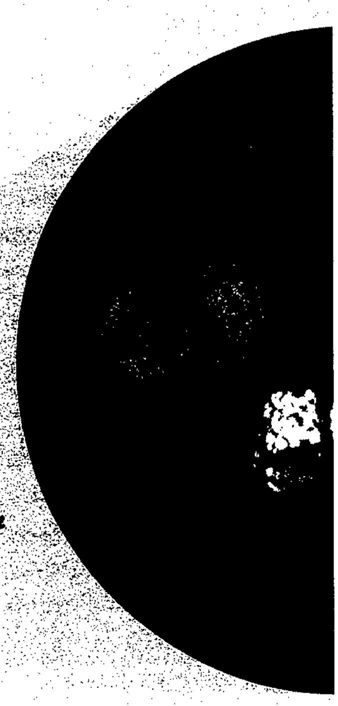
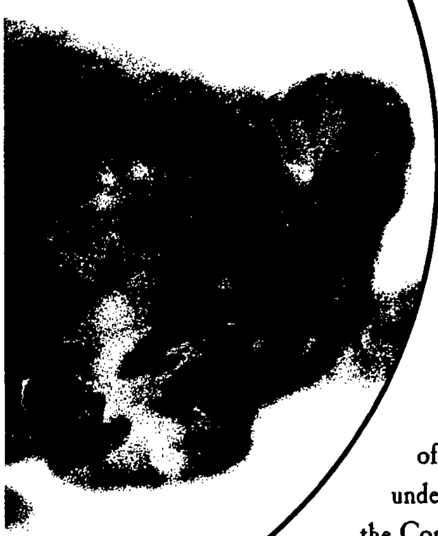


The forked structure on the end of the abdomen of this common springtail is the "spring" that propels these tiny animals into the air.

Ecosystem Processes



to fire; their numbers increase dramatically in the months following a burn.

"The impact of fire on arthropods is a current research focus for some entomologists, and we are finding at Eglin that fire-maintained longleaf pine areas seem to have greater arthropod biodiversity than surrounding areas where fire has been suppressed," said Conservancy Entomologist Krista Galley.

The springtail's presence is evidence of the health of an ecosystem. "They're used as indicators in the field," Snider said, since population depressions may mean the springtails are sensitive to herbicides or pesticides being used.

Their presence is good news for Eglin researchers, now in the fifth year of a six-year study of the largest single ownership of longleaf pine forest remaining in the world. The study, one of the largest restoration experiments ever undertaken, is a collaborative effort between the Conservancy, the University of Florida and the Tall Timbers Fire Management Program.

"What we've seen so far is that fire is definitely the best technique for restoration, especially for stimulation of the understory biodiversity," said University of Florida Professor George Tanner.

Researchers will continue to study aspects of restoring degraded longleaf pine sandhills at Eglin, including the role springtails play.

"I just find it amazing that when fire comes, these little wingless creatures with no method of escape survive, and their populations really respond positively," said Galley.

Snider, in helping identify springtails from samplings for the Conservancy, has discovered two new species at Eglin. He agrees the creatures he calls "cute" are critical to the ecosystem. "If it weren't for springtails we would be up to our necks in organic matter," Snider said.

Springtails are found all over the world in habitats ranging from rock crevices in Antarctica to the American Mojave Desert to the beaches in Key West.

The species living in shells and stones in the tidal zone actually stay submerged while the tide is in, taking in oxygen from the water.

Some springtail species live nine feet down in the soil while others exist on the top layer of the tree canopy. Some species favor fresh green plants while others feast on slightly decayed matter. Some are brightly colored; some are white. One species even produces juveniles that line up single-file behind the female and follow her wherever she goes.

April 2000 Volume 11◆Issue 4

Resource Issues Update

A Publication of Champion's Wildlife & Forest Policy Team

SFI Lessons

Champion has proposed a workshop where companies that have completed SFI 3rd party audits can share learnings from their field experiences. AF&PA and The Conservation Fund will serve as cosponsors with CIC in the one-day, invitation-only session that will follow the SFI Summer Conference in Portland, OR in June. The goal is to have representatives from audited companies and audit firms share learnings that could lead to SFI enhancements - - either in the standards, performance measures, and/or list of indicators.

Riparian Buffer Training in NC

Three employees from the Eastern Carolina Region attended a day-long session detailing the new riparian buffer protection rules for the Tar-Pamlico and Neuse river basins. The training provided a regulatory overview and interpretation discussion and visits to 6 field sites for examination of the application of the new rules. Specifically, the riparian buffer rules mandate protection of a 50' area immediately adjacent to all surface waters including perennial and intermittent streams that are locatable on USGS quadrangle maps or county soil survey maps. Within the buffer, the regulations place limitations on the amount of harvest, type of equipment utilized, and other management considerations.

Classified: Streams

Weldwood's Hinton Division has completed pilot studies which enable them to define watershed basins using an automated GIS program, and classify streams by channel type and bed material size. Once all basins are defined and all streams classified, the data will be used to develop the most appropriate management prescriptions for each site, such as type of crossing to install, or which streams are high value for fish, etc.

Washington SFI Plans

The Washington SFI State Implementation Committee is working to engender support of SFI and Voluntary Verification Audits with state opinion leaders. Their efforts have been stepped up in light of the Washington Department of Natural Resources recent overtures towards FSC certification for its 5 million forested acres.

Forest Roads Workshop

The South Operation of the MidSouth Region contracted with Chris Isaacson of Preceda and Dr. Robert Tufts of Auburn University to conduct a Forest Roads Workshop for Champion employees and contractors on April 5th and 6th in Moulton, AL. Customized lecture and field work focused on road construction and road maintenance problems, and BMP work after harvest.

Eagles in GA

At least two eaglets were discovered in a bald eagle nest by Donna Hardy in the Georgia District of the MidSouth Region. Georgia officials were aware of the location of the nest; however, based on an aerial survey conducted earlier this year, they believed it to be inactive.

Lessons in Hardwood Management

Dr. Bob Kellison, Director of Forest Technology, visited the MidSouth Region on March 21-22, and instructed foresters on hardwood management techniques and how they complement Champion's Forest Patterns. Bob offered to return to the MSR to delineate the line separating suitable pine sites from sites where grade hardwoods should be managed.

Tour of Special Place

A local chapter of the Sons of Confederate Veterans conducted tours of Eastern Carolina Region's Confederate Fortifications Special Place on Saturday, April 8th. The fortifications are a series of hand-dug trenches, bunkers, and ammunition storage areas. They were constructed to prevent capture of the Wilmington to Weldon Railroad by northern troops during the civil war. Tours and interpretations of the site are conducted in the spring and fall, providing an exciting view into local history.

Update on GCPEP

Ad Platt and Joe Cox represented Champion's Gulf Atlantic Region at a recent meeting of the Gulf Coastal Plain Ecosystem Partnership (GCPEP). As the GCPEP matures, it is better defining it's region of concern as those lands from the Escambia to the Choctawhatchee River, and from the Conecuh NF to the Gulf (including the barrier islands). Membership in the partnership is also evolving. The NF in Florida has withdrawn (not physically within the region, but still supporting), and several other organizations have petitioned for membership (including FL DEP, John Hancock, and Pensacola Naval Air Station, Whiting Field). GCPEP helps the GAR in a number of ways. Examples include assistance in developing management guidelines for the bog frog, development of practical field guides on native grasses for restoration and road stabilization, and assessment of streams on our landbase. Champion has provided office space for three GCPEP employees in its Blackwater Office, and expects that to grow, as the GCPEP is currently interviewing for a conservation biologist.

Law Reviews Revised

Reviews of Maine's and Michigan's state threatened and endangered species laws have been revised. The reviews, originally published in 1997, have been revised to include recent modifications to each state's list of T&E species; and in the case of Maine, recent amendments to its laws that more clearly define take. The updated reviews can be found in the SFI Library on Lotus Notes, or hard copies can be requested from Jim Sweeney (sweenj@champint.com).

Managing A Tradition

In Maine, there is a unique long-standing tradition of public recreational use of private forest land; and with nearly 2000 miles of roads, there has also been problems of abuse. The NER Public Use Team has taken important steps to manage inappropriate behaviors and environmental risks. The center piece of this strategy is a partnership with users of fee-owned lands called Champion Stewards. Members pledge to demonstrate a high level of stewardship ethic, comply with NER's public use policies, encourage others to exercise responsible and respectful behavior, and report abuses and problems observed. The annual $20 administrative fee entitles a Champion Steward to a vehicle decal, public use atlas, policies, and news letters.

End Run Fouled?

Conservation groups, after loosing in U.S. courts have taken their claims that forestry violates the Migratory Bird Treaty Act to the Commission for Environmental Cooperation. The CEC, made up of Canada, the U.S. and Mexico has been asked to censure the U.S. for failure to enforce the MBTA against loggers and logging operations saying harvest takes birds. AF&PA filed a detailed legal brief in support of the U.S. response to the CEC pointing out U.S. courts have repeatedly found the take provisions within the MBTA do not apply to forestry, a fact omitted from the conservation group's filing. The brief goes on to point out that it would be inappropriate for the CEC to interfere with the authority of U.S. domestic courts to determine U.S. domestic law.

More Active Eagles

A Bald Eagle nest has been located by Champion's Gulf Atlantic Region on the Styx Forest in western Florida. The nest is protected as part of a buffer to a pine-hardwood bottom. The nest was confirmed to be occupied during helicopter recon this spring; two adults and one fledging eagle have been observed. The GAR has entered the location into its GIS mapping system and has established operational restrictions in line with USF&WS guidelines. The hunting club leasing this property has also been instructed to minimize their activity around the nest during the nesting season (Nov - Mar).

SHARE Gets Grant

The Maine Atlantic Salmon Commission has approved a one year $90,000 grant for Project SHARE. The funds will support a Grant Writer/ Executive Secretary and a technician to help watershed councils develop management plans. These positions will provide an opportunity to expand efforts to conserve salmon habitat in the seven major wild salmon rivers. In 2000, Champion International and Georgia Pacific completed a three year sponsorship of Project SHARE's Executive Secretary. During this time, Project SHARE has become nationally recognized for its approach to salmon conservation making awards of this type possible.

Published by:

- Carlton Owen
- Jim Sweeney
- Cheryl Tant

Please direct any inquiries regarding this publication to (864)370-7232.